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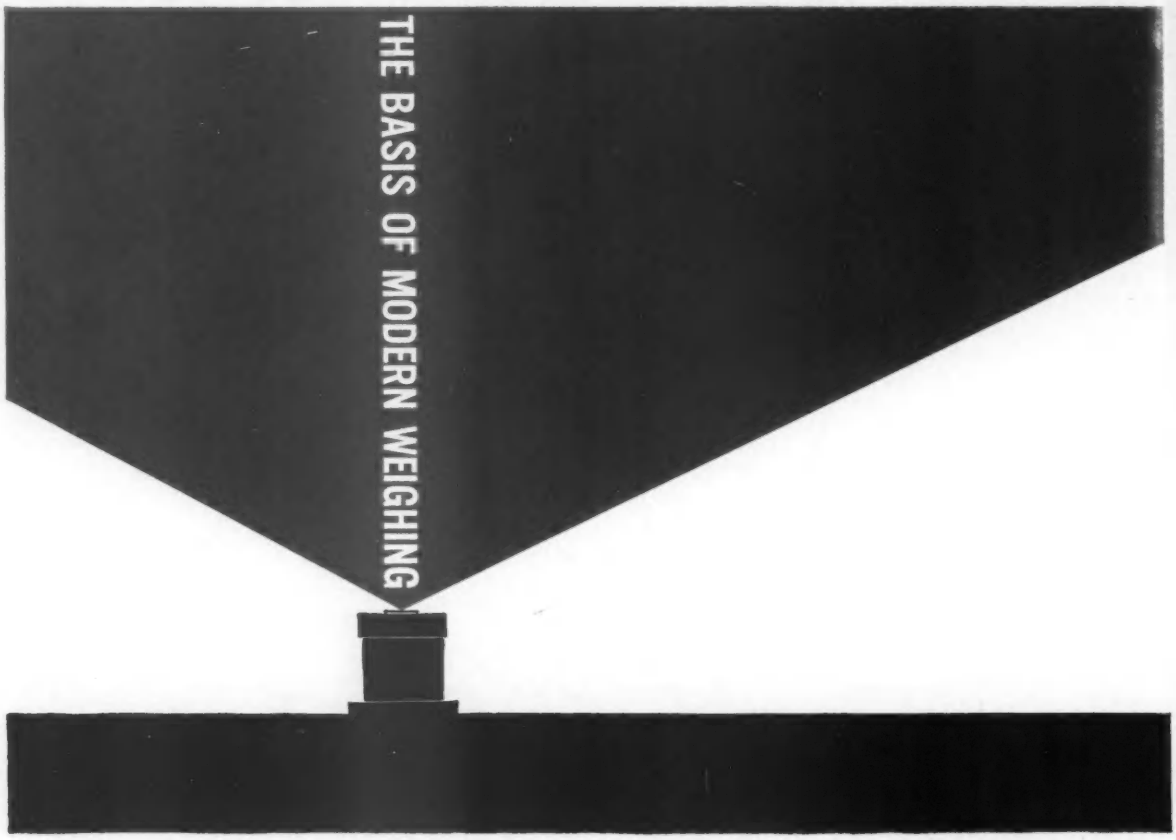

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VOL 3 NO 26 AUGUST 1960

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SPECIAL FEATURES

The meaning of Ifac
The tremendous international congress that ended in Moscow last month is weighed up for CONTROL *readers by five celebrities in the control engineering field. Our special guest critic is Dr JOHN G. TRUXAL, of the Brooklyn Polytechnic Institute, who gives an American evaluation of the congress. In the British team, Dr J. H. WESTCOTT of Imperial College concerns himself solely with theory, R. J. A. PAUL of the College of Aeronautics, Cranfield, considers both theory and equipment, R. J. REDDING of Evershed & Vignoles looks at components and their uses, and independent consultant Dr D. B. FOSTER assesses the industrial applications* 84

More control on machine tools
E. J. C. FOWELL of R.A.E. reports the 1960 International Machine Tool Exhibition at Olympia, and concludes that the industry is less stuck in the mud than it likes to pretend 97

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A. J. SADLER and P. A. TURNER of A.E.I. predict a rosy future for this hardy new semiconductor application 101

Controlling nuclear power—*1*
The Editor gives a gentle introduction to a new series of articles, each by an authority in his field, on the fascinating problems that have to be faced by this evolving industry 104

A lull in computers
Manchester University's R. A. BROOKER finds the few tit-bits that were served at the latest Conference of the British Computer Society 108

Look at America
*Prof. J. LOWEN SHEARER, ROBERT SCHER and KARL REID, of the Massachusetts Institute of Technology, search out the latest American developments. Their news-letter is a 'SPECIAL Feature' this month to mark its first appearance—*Look at America *will be a regular feature in* CONTROL *from now on* 110

Transfer-function manipulation may ease simulation—*2*
F. WALKER, of Manchester College of Science and Technology, finishes his explanation of how fairly complex servo-systems can be simulated with a limited number of function units 113

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LOOKING FOR A JOB? CONTROL *carries the best jobs going in instrument and control engineering.* **SEE PAGE 157 AND ONWARDS**

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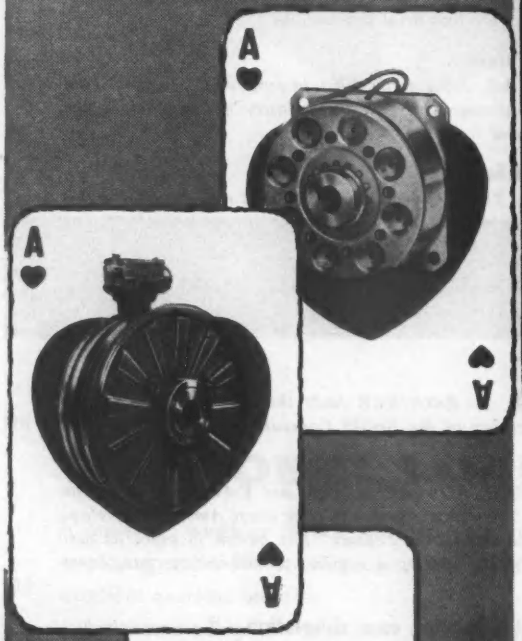

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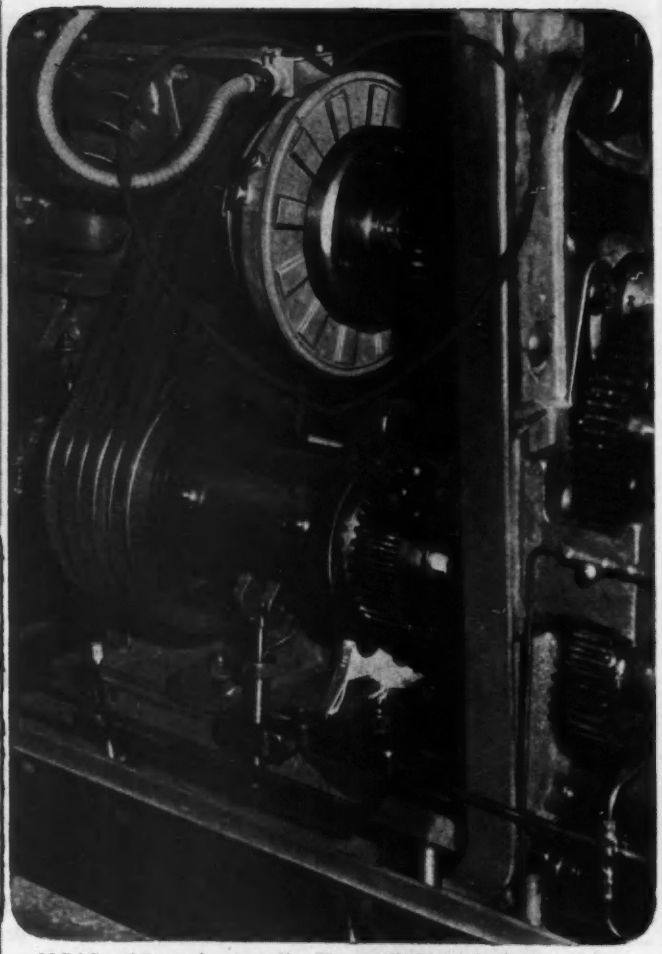

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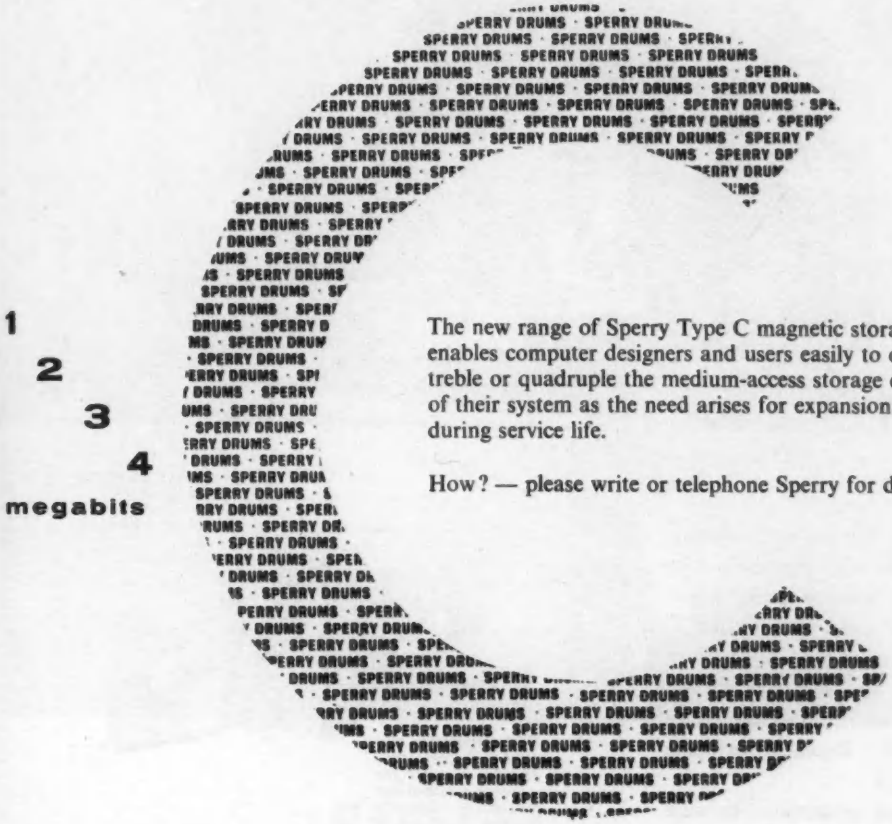

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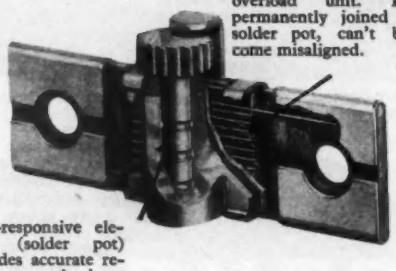

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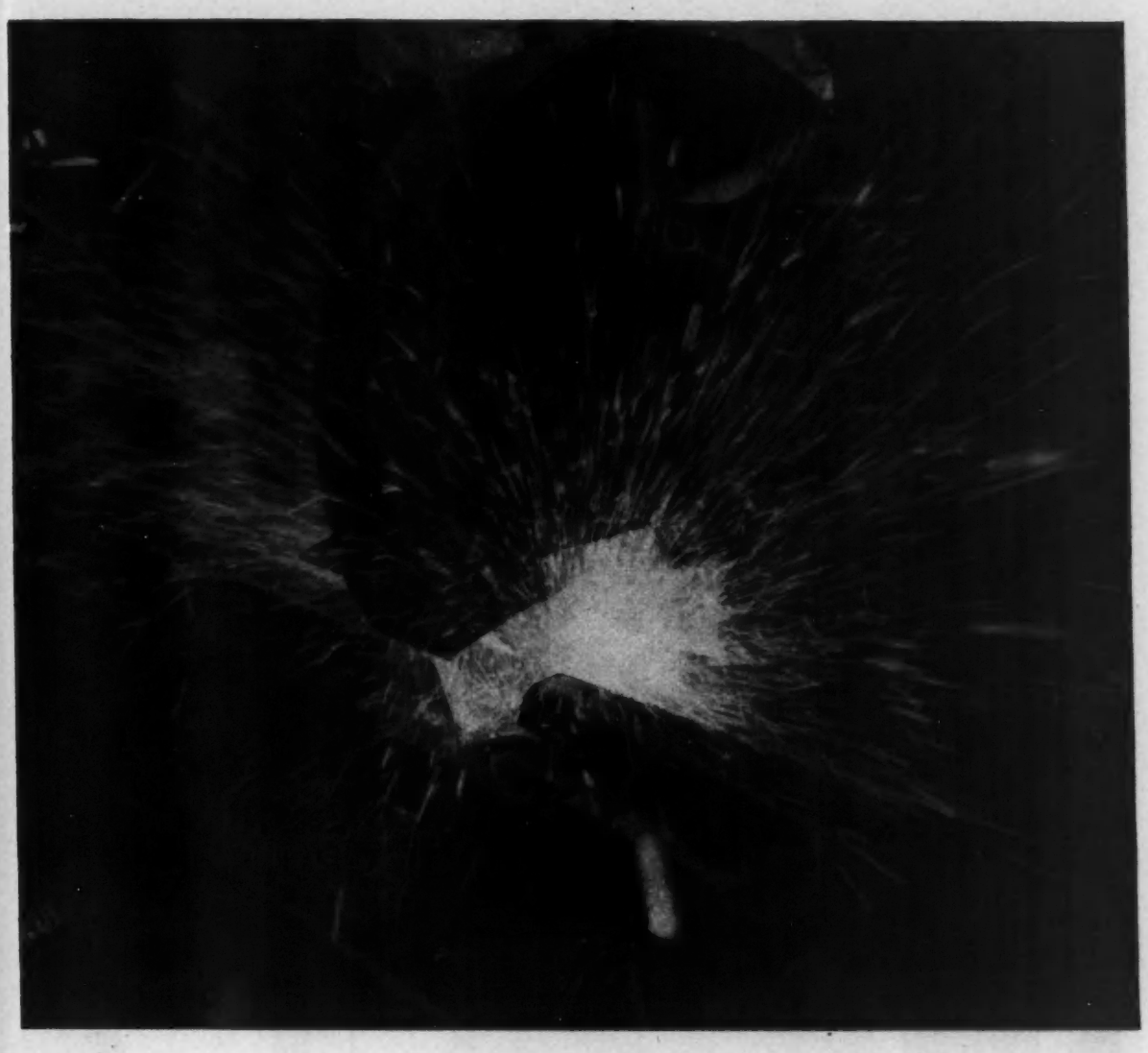

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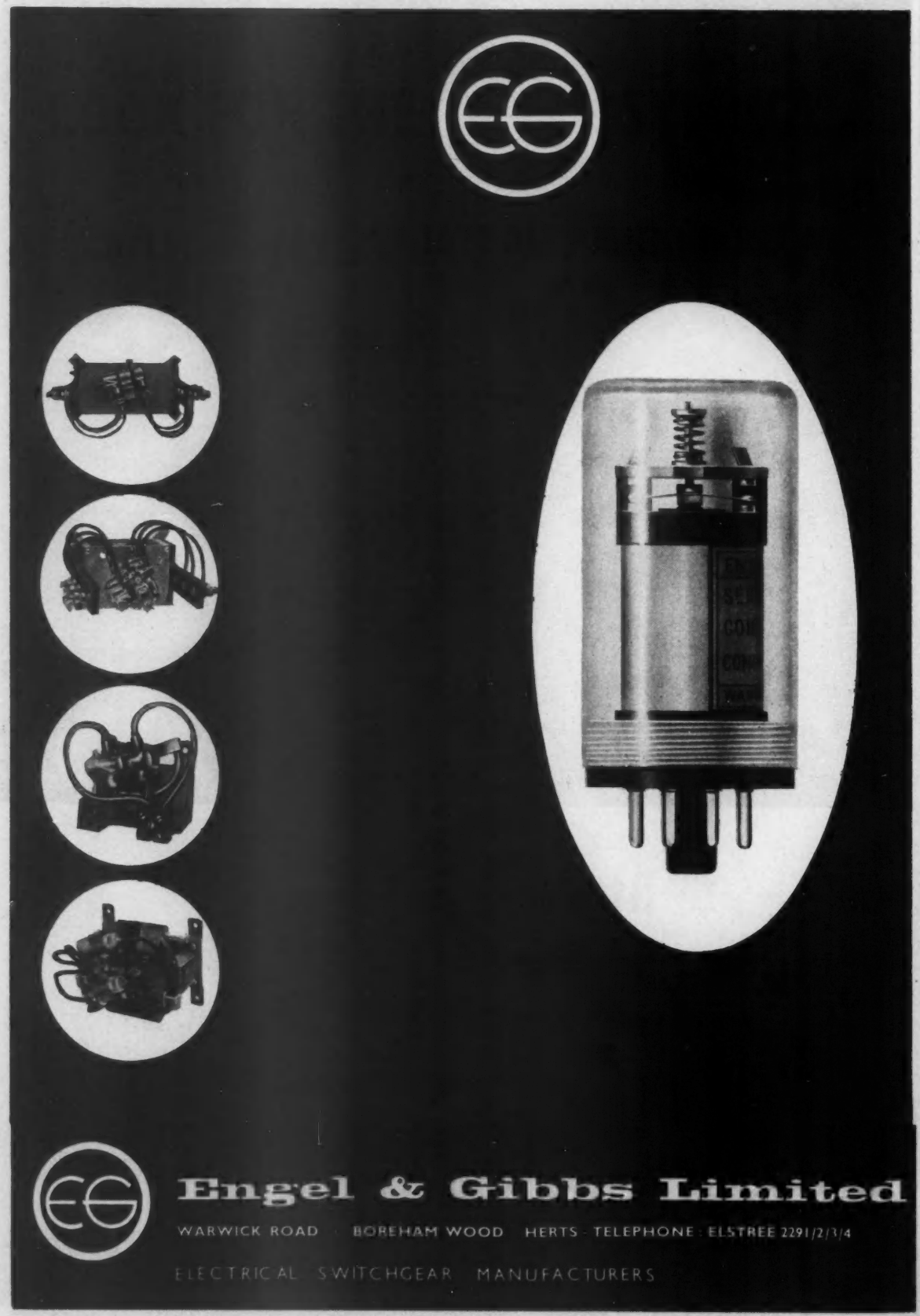
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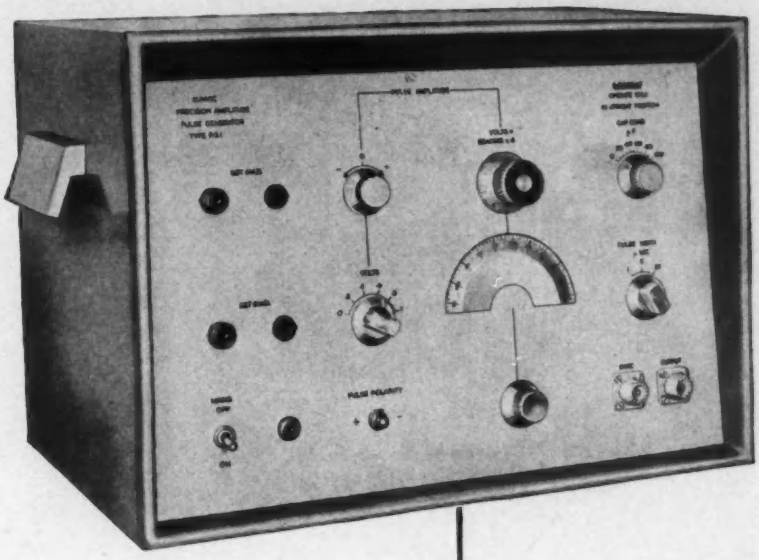

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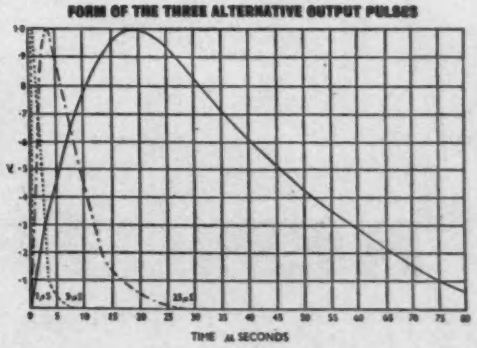

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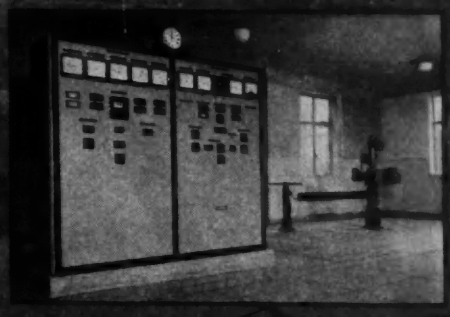

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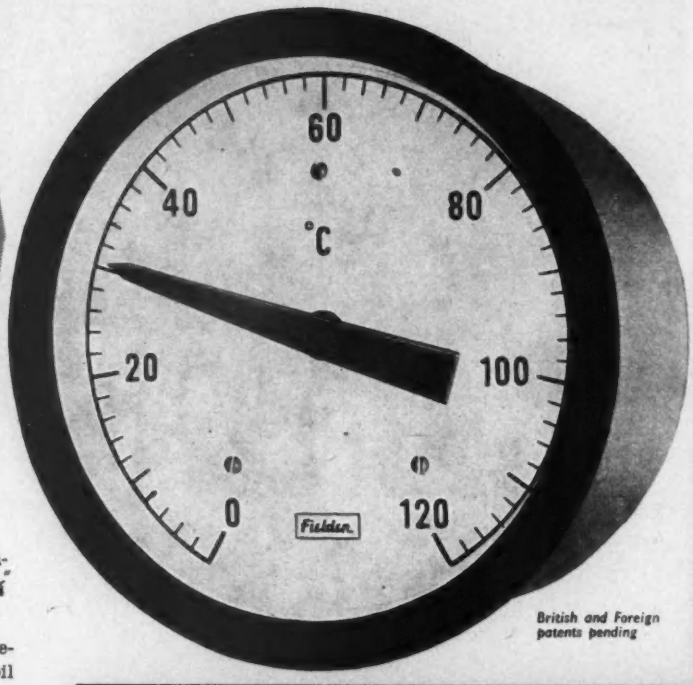

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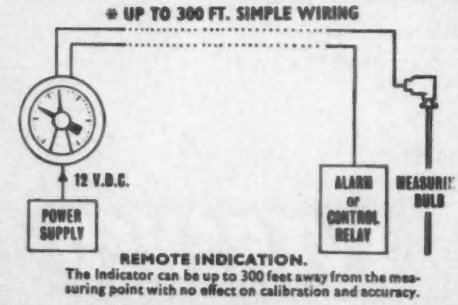

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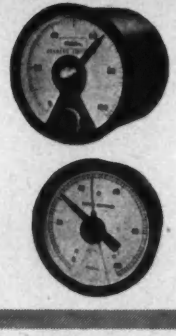

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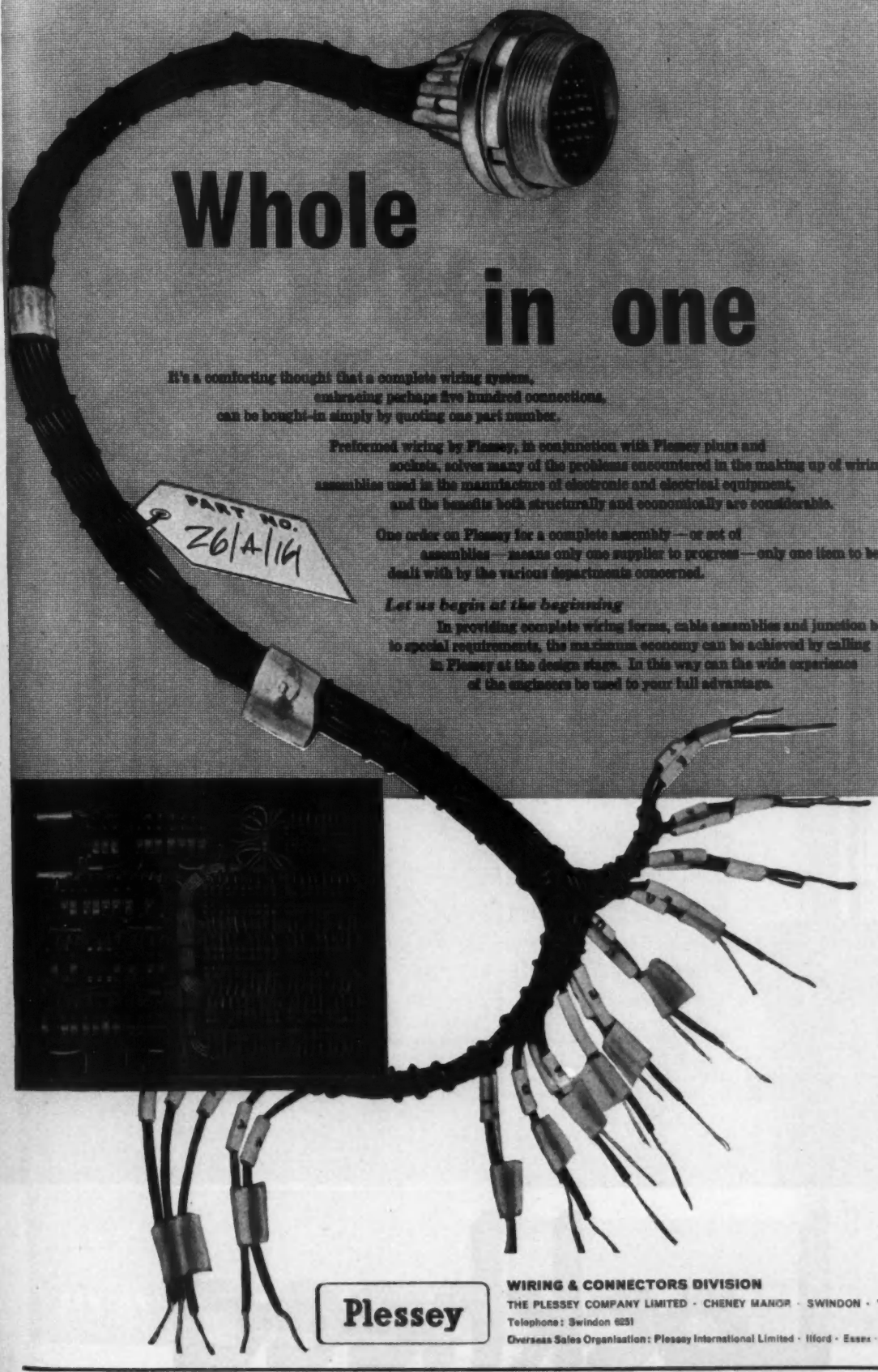

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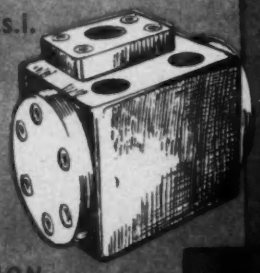

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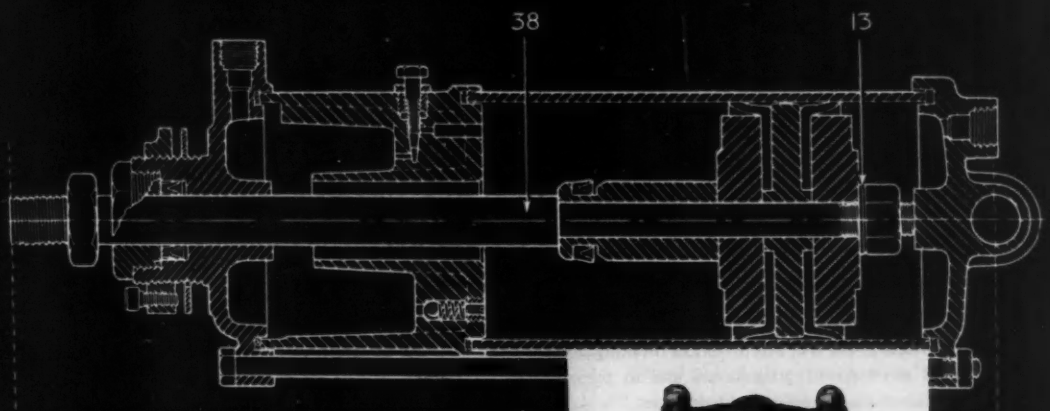

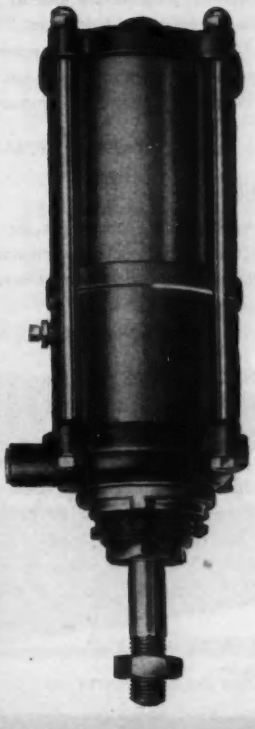

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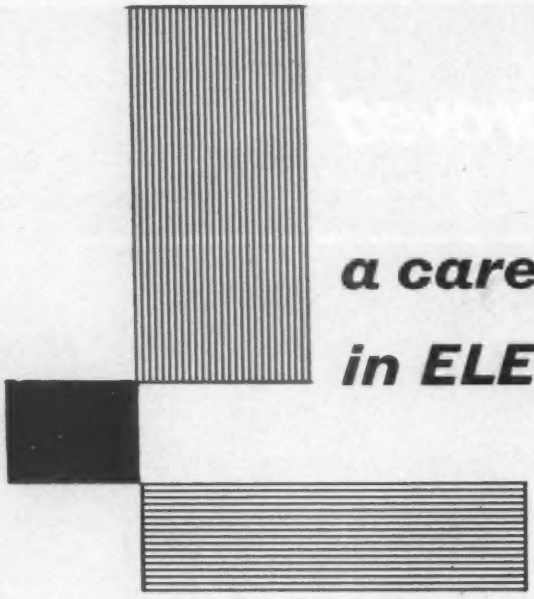

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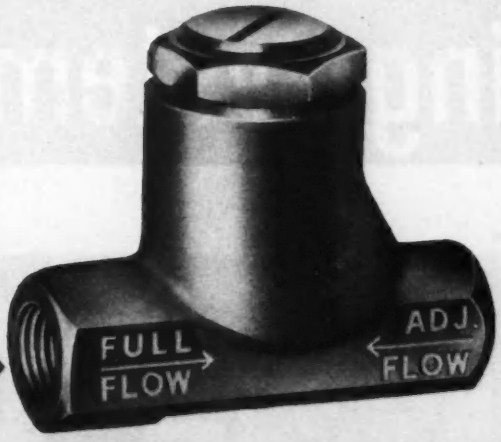

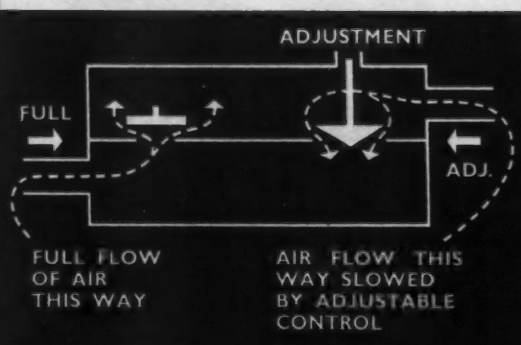

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105447	539582
459233	937562
811278	423038
532485	902475
114857	521054
984735	284731
927411	883746
210473	937561
567482	109235
665820	991375
857395	274837
948573	198573
195847	958473
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859483	210084
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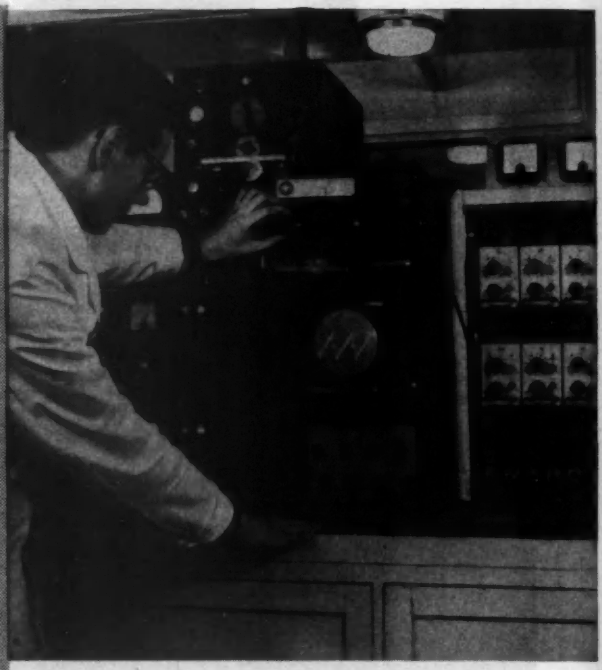


DIDAS receiving and recording in laboratory conditions

- Fully Transistorized
- Extremely High Speed
- Compact
- Reliable
- Modern Construction
- Rugged but light

Speedy measurement and analysis of data has become a necessity in modern industry. Armstrong Whitworth Aircraft have developed data handling systems for measurement and remote control. The data can be transmitted at the speed of light by radio, or by cable link, with extreme accuracy. In one system (the DIDAS vehicle system), over 250,000 different readings can be obtained in one minute. Analogue/digital and digital analogue convertors, working at over 50,000 conversions a second, eliminate processing bottlenecks. Systems can be engineered to customers' requirements.

SIR W. G. ARMSTRONG WHITWORTH AIRCRAFT LIMITED, Baginton, Coventry, England
(A member of Hawker Siddeley Aviation)

HADDON

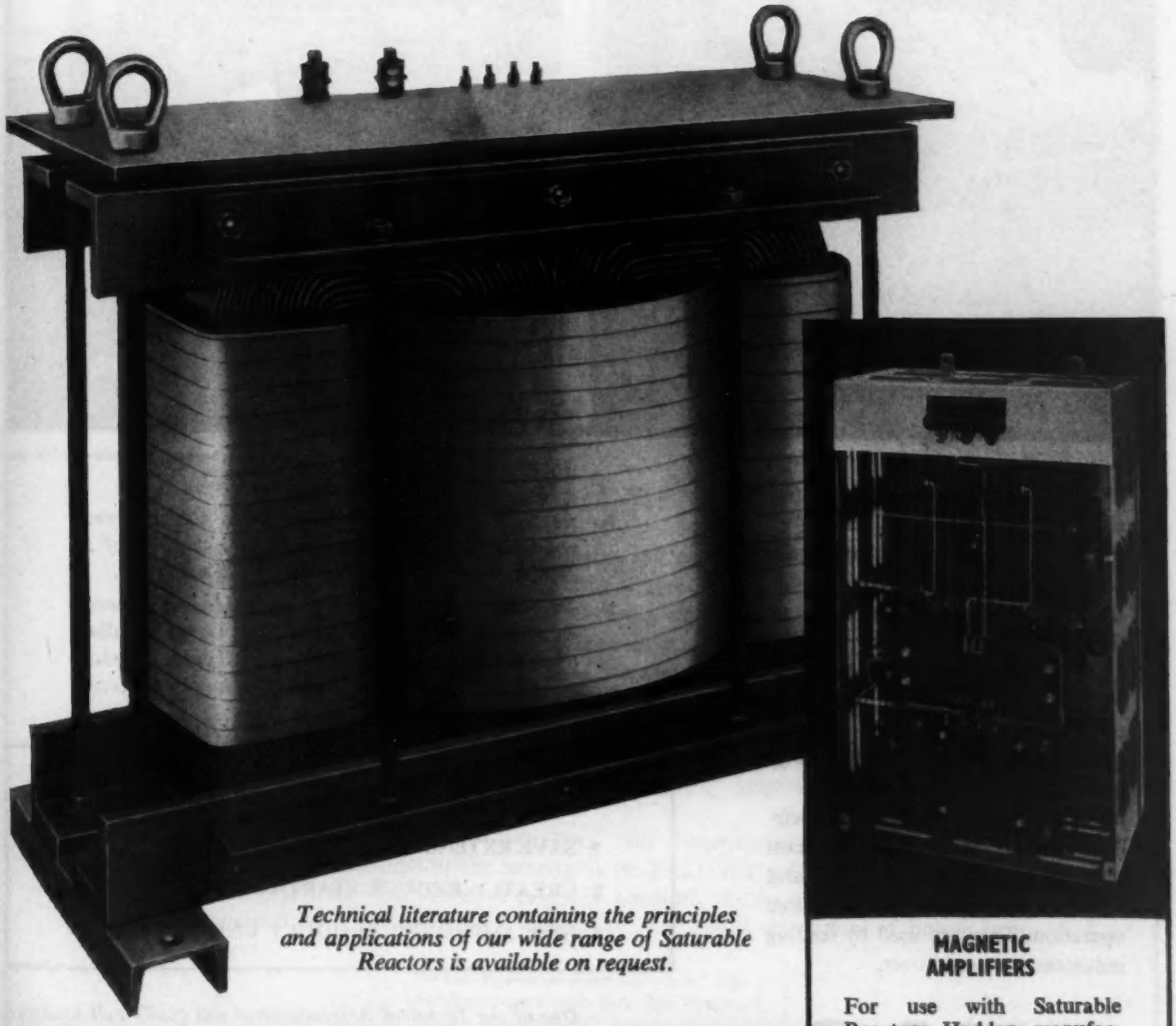
STANDARD

SATURABLE REACTORS

TRANSDUCERS

Haddon **"STANDARD"** Saturable Reactors—Transductors operate from conventional A.C. line Voltages and provide a choice of D.C. Voltages for Control Windings. Selected from a wide range of individually designed and manufactured **SPECIALS** over past years, the **HADDON STANDARD RANGE** enable the discerning engineer to select **STANDARD EQUIPMENT** for Specific application. 416 standard single-phase designs cover the range 1 kVA to 300 kVA.

They provide the best method of stepless control in both long-term economies and high performance standard.



Technical literature containing the principles and applications of our wide range of Saturable Reactors is available on request.

MAGNETIC AMPLIFIERS

For use with Saturable Reactors Haddon manufacture a standard line of Magnetic Amplifiers.

Operating from 200/250V 50/60 c/s single-phase supply, with input of 0–5 mA DC in 2000/8000 ohms.

Illustrated above is the 1000W Magnetic Amplifier

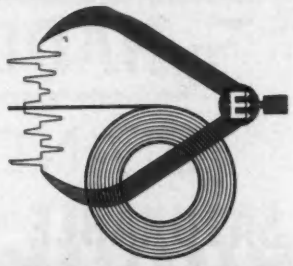
HADDON

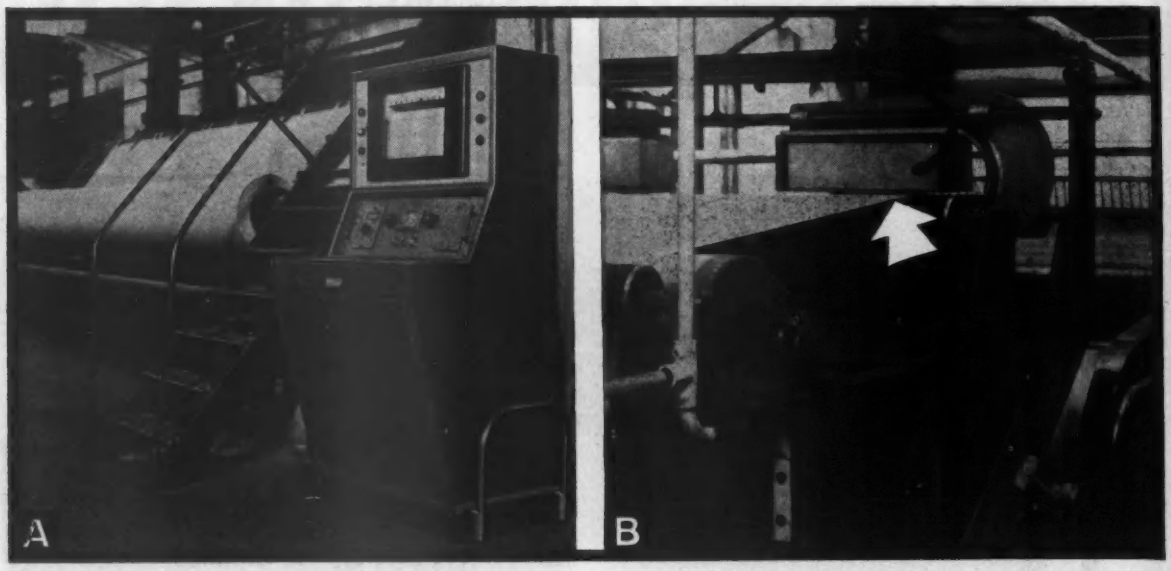
HADDON TRANSFORMERS LIMITED

Victoria Park Industrial Estate, Field End Road, Ruislip, Middx.

Telephone: Byron 9444-8 Telegrams: Hadtrans, Ruislip

Step up your plant efficiency





(Photographs by courtesy of the Bowaters Organization and I.C.I Ltd.)

EKCO Nucleonic Gauges provide an ideal solution to many of the problems connected with *quality control* of materials produced by continuous-flow processes.

They give continuous, accurate measurement of thickness or weight per unit area, at the earliest possible stage of manufacture, without contact with materials.

EKCO Reliability. All EKCO Nucleonic Gauges are built to maintain their high standards of efficiency and to give easy, *low-cost*, trouble-free operation. They are used by leading industries the world over.

A. *An Ekco Automatic Standardisation Gauge shows prominently in this front view of the dry end of a 280 in. Fourdrinier Machine producing newsprint.*

B. *Two measuring heads, one on each side of the sheet, are employed in this Ekco Nucleonic Gauge installation. The machine is a Bridges 3-bowl calender, producing PVC coated fabric in one of the largest factories manufacturing leather cloth in Great Britain.*

Because Ekco Nucleonic Gauges work to exceptionally low limits of tolerance they:—

1 SAVE EXTENSIVELY ON MATERIALS

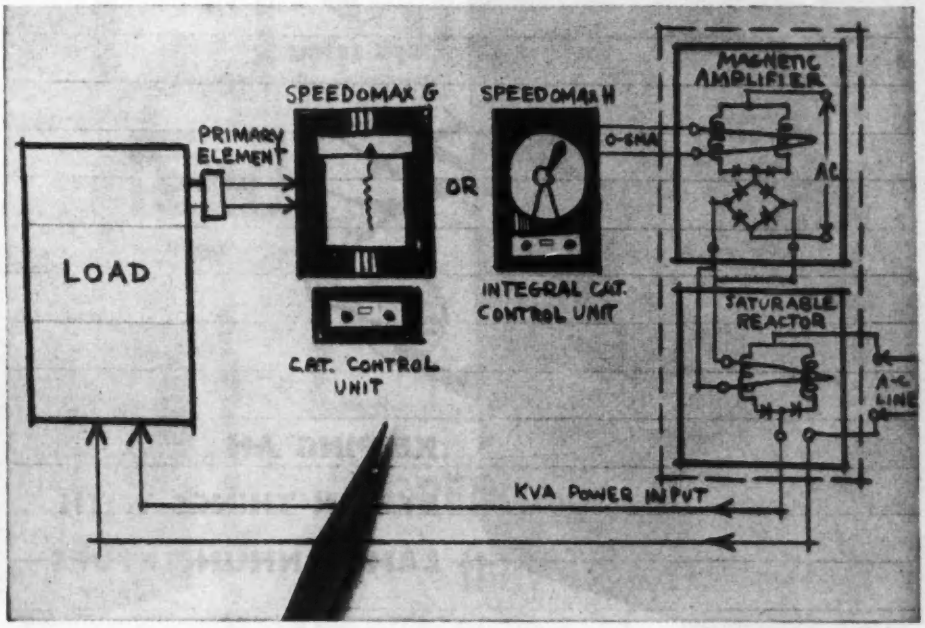
2 GREATLY REDUCE START-UP TIME

3 GIVE IMPROVED PRODUCT UNIFORMITY

One of our Technical Representatives will gladly call to discuss how Ekco Nucleonic Gauges can step up your plant efficiency.

EKCO nucleonic gauges

EKCO ELECTRONICS LTD · SOUTHEND-ON-SEA · ESSEX · SOUTHEND 49491



Now... Stepless control of Electric Heat Input with L & N's new C.A.T. control system

If your process uses electric heating equipment it will pay you to learn about L & N's new current-adjusting type control for continuous efficient power output in saturable core reactor systems. It is already in use on applications like crystal growing, strip annealing, nuclear material testing, glass feeder control and electric Furnaces generally. This method permits stepless and rapid regulation of power output over the entire operating range of saturable core reactors. The wide range of adjustment of proportional, reset and rate actions facilitates tuning the system to your process, product and production.

C.A.T. control is a complete system consisting of: (1) A primary Element, (2) Speedomax 'R' Recorder, (3) C.A.T. Controller, and (4) A Magnetic Amplifier and Saturable Core Reactor in one unit.

Heart of the system is the C.A.T. Controller. Any temperature change detected by the primary element and measured by the recorder is fed to a C.A.T. Continuous d-c output of the unit over 0 to 5 ma range drives a magnetic amplifier, the d-c output being fed to the control windings of a saturable core reactor for continuous regulation of power input to the process.

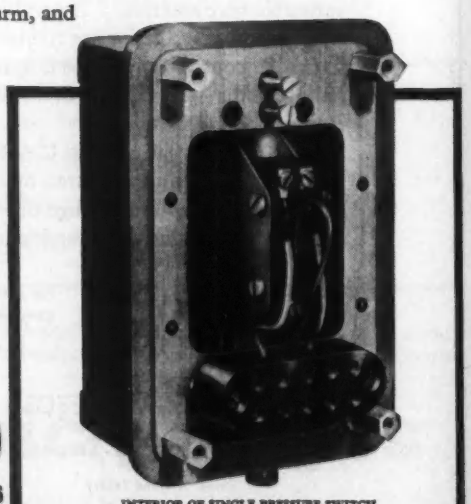
For more information contact your nearest Field Representative or write for Data Sheet ND4(7a).

INTEGRA, LEEDS
183 Broad Street
Phone: Midland 1453/5

& NORTHRUP LTD.
Birmingham 15
Telegrams: Flometer, Birmingham

KEEPING AN EYE ON THINGS WITH LAMP ANNUNCIATORS

There is a range of Firth Cleveland lamp annunciators to keep an eye on things for you. These are designed for alarm and advisory functions wherever visual signals are required. Where you need the additional protection of an audible signal, we can arrange a bell, hooter or siren to be connected in parallel. A muting switch allows you to silence the signal once your attention has been attracted, and when conditions return to normal there is an automatic reminder for you to reset it. We have designed the case so that you can mount it to suit yourself—semi-flush or projecting from the panel. You can use these annunciators in conjunction with the Firth Cleveland capsule operated pressure switches for liquid level alarm indication. Single switch units are available for high or low alarm, and double switch units where dual protection is required.



INTERIOR OF SINGLE PRESSURE SWITCH

The range of Firth Cleveland industrial instruments also includes Hydrostatic tank contents gauges and pressure relief valves all of which are complementary to each other. We shall be happy to send you full details.

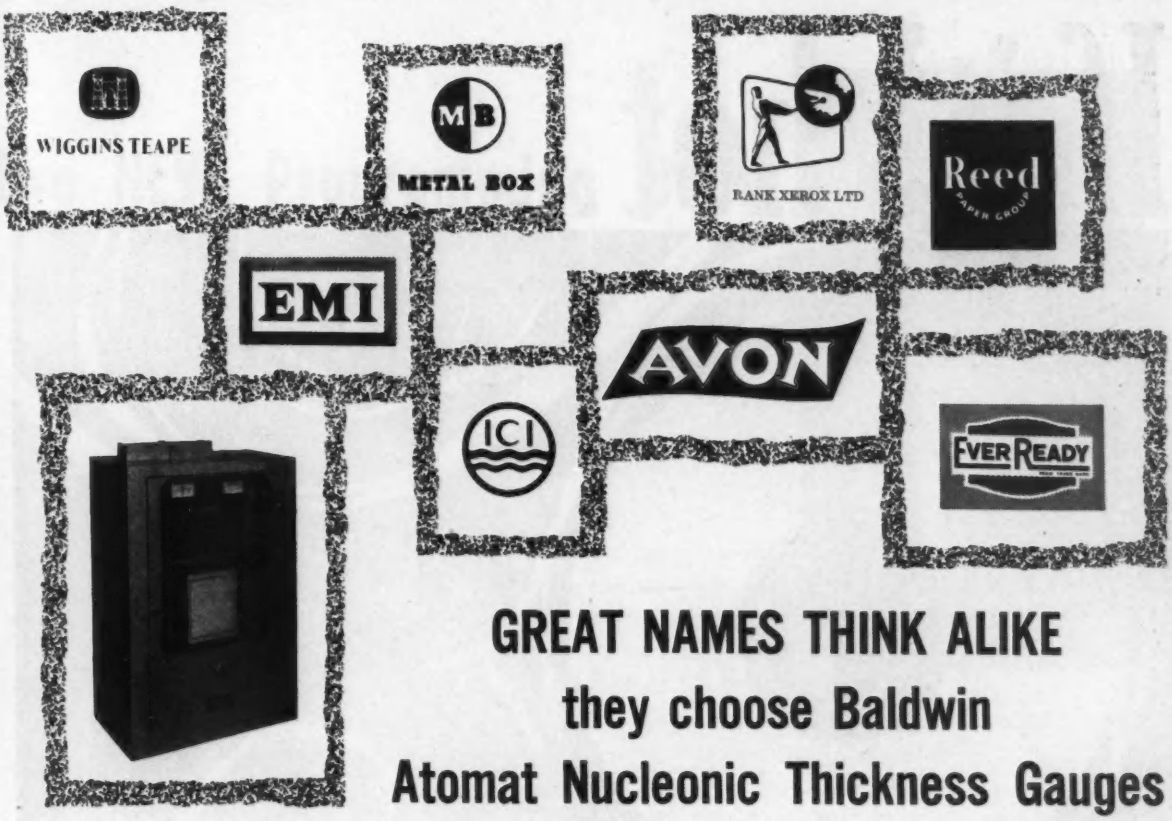
FIRTH CLEVELAND INSTRUMENTS LTD

Stornoway House, Cleveland Row, London, S.W.1. Telephone Whitehall 2166

BRANCHES: BIRMINGHAM · MANCHESTER · GLASGOW · STOCKHOLM · COPENHAGEN · BALLARAT · SYDNEY · JOHANNESBURG · HAARDEN · MILAN · NEW YORK · BRUSSELS · MANNHEIM

A MEMBER OF THE FIRTH CLEVELAND GROUP

CIC310



GREAT NAMES THINK ALIKE

they choose Baldwin

Atomat Nucleonic Thickness Gauges

Look on the machines turning out some of Britain's most famous products and you'll find Baldwin Nucleonic Gauges saving material, labour and time! Yet, although Baldwin gauges are used more and more throughout industry, there's no question of a standard unit for all machines. Baldwin gauges are—and always will be—tailored individually to the measuring job in hand.

SO THAT'S POINT ONE . . . **BALDWIN DESIGN AND MAKE COMPLETE CONTROL GAUGE SCHEMES FOR SPECIFIC INSTALLATIONS**

Then there's Baldwin Automatic Standardisation and Control. Baldwin gauges not only check materials in production, but can correct the machine when production limits are exceeded. And Baldwin gauges *even check themselves*, automatically compensating for any radioactive source decay.

AND THAT'S POINT TWO . . . **CONSTANT INSPECTION — CONSTANT ASSURED ACCURACY**

ADD THESE OTHER POINTS AND IT BECOMES OBVIOUS WHY BRITAIN'S TOP MANUFACTURERS CHOOSE BALDWIN

* **SAVINGS IN TIME AND MATERIAL**
* **CALIBRATION IN YOUR USUAL UNITS OF MEASUREMENT**
* **HIGH ACCURACY**
* **MINIMUM MAINTENANCE**

Ask Baldwin for their brochure C-124; it carries clear and concise information—but no obligation on your part.

INSTRUMENT DIVISION

Baldwin Industrial Controls

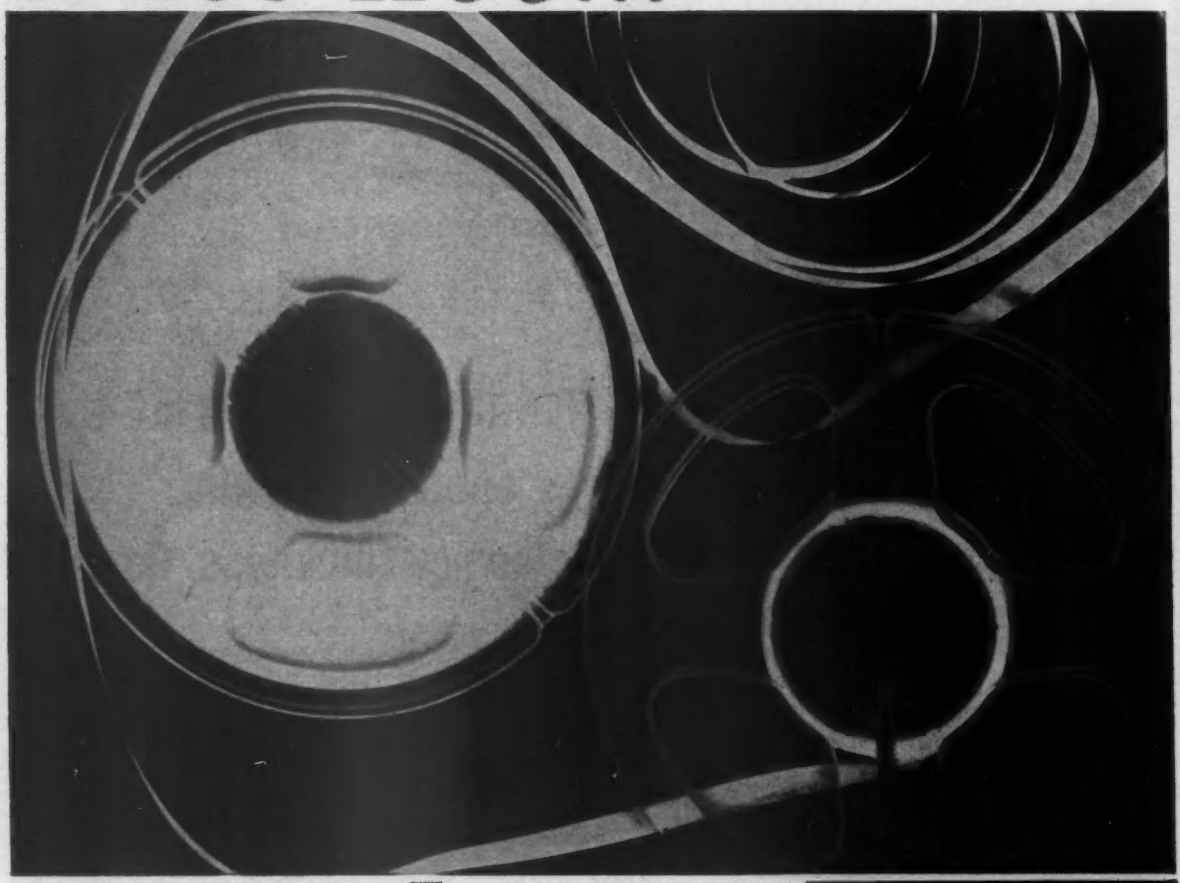
Baldwin Instrument Company Ltd., Dartford, Kent

Telephone: Dartford 20949 & 26411 Cables & Telex: Baldwin, Dartford

A HARPER GROUP COMPANY

834

If it's hot...



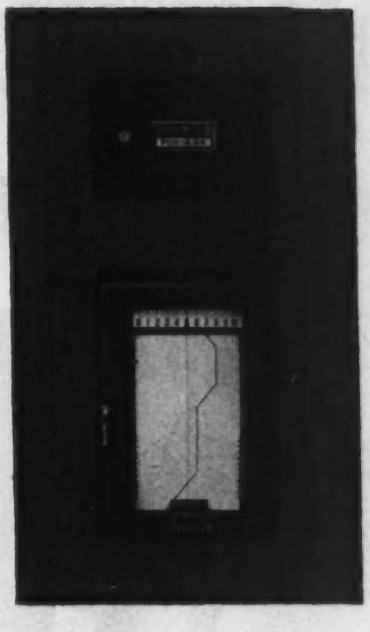
record it on Epsylon

6-speed multi-channel recorder

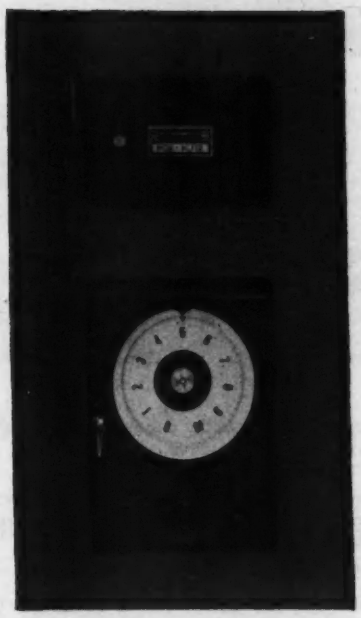
● **EPSYLON** **Magnetic Tape Recorders provide the most versatile recording facilities for research, development and control. A few of the interesting features of the Epsylon range are: wide frequency range from DC; tape speeds up to 150 ins./sec; 16 channels per inch; capacity 5,000 ft; endless loop; remote control; choice of speed ranges; recording and replaying at different speeds. Eminently successful applications include data recording in aviation, missiles, machinery, and other industries, seismography, process control, monophonic and stereo sound, digital computing. If it's hot (or cold, fast or slow, a tune or a strain, tremor or thump, or a digit) please let us send you full details of the Epsylon range.**

EPSYLON INDUSTRIES LTD Faggs Road, Feltham, Middlesex, England. Telephone: Feltham 5091
A Member of the Stone-Platt Group

Two NEW Programming Units for use with "FOSTRONIC" Self-Balancing Potentiometric Controllers



The PCU-1B/24 unit is contained in a wall mounting and flush fitting black enamelled metal case and comprises a continuously running synchronous motor with reduction gearing driving a programme cam, a spring loaded cam follower in turn moves a sliding contact over a calibrated wound slide wire which forms part of the self-balancing potentiometer measuring circuit, the movement of the sliding contact thus progressively varies the effective set point (balancing temperature) of the controller according to the profile of the cam.



The unit is available with basic speeds of 2, 6, 14, 16, 20 and 50 hours per one revolution of the programme cam spindle. Interchangeable gear wheels supplied with the unit permit the rate of revolution to be halved or doubled at will. With this unit a separate cam is required for each individual programme.

The PCU-1C/12 unit is generally similar to the PCU-1B unit, but the programme cam spindle drive is through a series of impulses from an electronic timer which is triggered once every minute by a cam operated switch in the programme unit. The frequency of the impulses is constant, but the duration of each impulse is determined by the setting of the electronic timer which can be set to give impulse durations of from 0.5 seconds up to 20.0 seconds thus the basic speed of the programme cam spindle (one revolution per two hours with halving and doubling gears) can be reduced from a factor of 3-1 down to a factor of 120-1. This unit is ideally suited for programmes requiring a constant rate of rise or fall throughout the programme. Only one cam is required and the rate of rise or fall is determined by the setting of the Electronic Timer Unit.

These programme control units may be used with the "FOSTRONIC" range of Indicating Controllers, Disc Chart Controllers and Strip Chart Controllers.

For full details contact:

RESILIA **FOSTER**

GOLDEN JUBILEE YEAR 1960

FOSTER INSTRUMENT CO. LTD., LETCHWORTH, HERTS., ENGLAND

Members of B.I.M.C.A.M., S.I.M.A. and S.I.R.A. *Telephone: Letchworth 984-5-6* *Telegrams: Resilia, Letchworth*

Advt/WT/18/F

Circle No 25 on reply card for further details

For protection
against flame-failure

FLAME-FAILURE & IGNITION CONTROLLERS TYPES 700 & 701

*
For gas or oil-fired systems
*
Completely reliable
*
Extremely versatile
*

These high-quality Controllers eliminate the dangers arising from flame-failure, and are effective in almost all types of gas or oil-fired furnaces. They employ an infra-red-sensitive photo-cell to 'see' the flame in furnaces, which discriminates between flame and furnace-radiation. The photo-cell reacts instantly to flame-failure and, should this occur, the fuel supply is immediately shut off by an electronic control unit.

Two Controllers are available. The Type 700 is semi-automatic (with provision for automatic purge cycle) and the Type 701 is a fully-automatic relight unit

Other Controllers operating on flame-conductivity or flame-rectification, and complete installations, are also available.

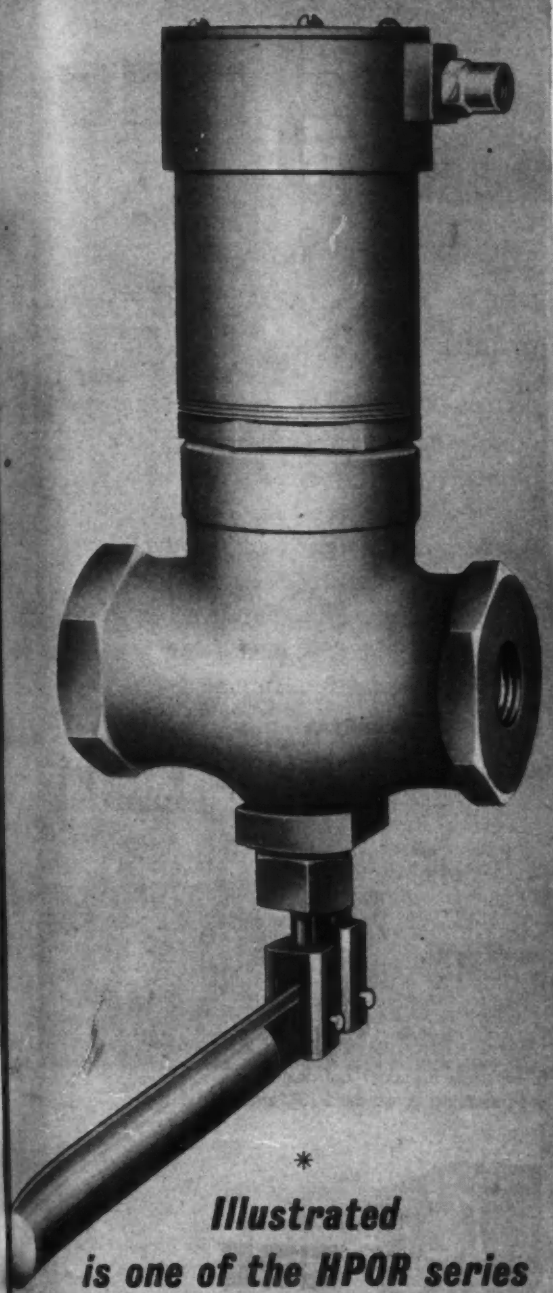
Further details gladly supplied on request.

ETHER LIMITED

ENQUIRIES, SALES AND SERVICE:
CAXTON WAY, STEVENAGE, HERTS.: STEVENAGE 2116
TYBURN ROAD, ERDINGTON, BIRMINGHAM, 24: EAST 0276
Representatives throughout the U.K.
Agents in all principal countries

Circle No 26 on reply card for further details

...and to complete your installation



SOLENOID VALVES

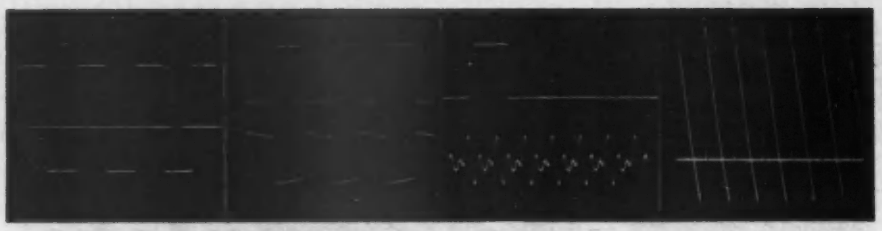
One of a range of highly-efficient solenoid valves, the HPOR is designed for use with all types of fuel oil. A lever mechanism ensures a smooth hand-reset operation. The valve is held open electrically and closes if the current fails. It will not then re-open until the hand-reset mechanism is operated.

Many other types of solenoid valve are available in the ETHER range for use with town gas, bottled gases, air and many fluids.

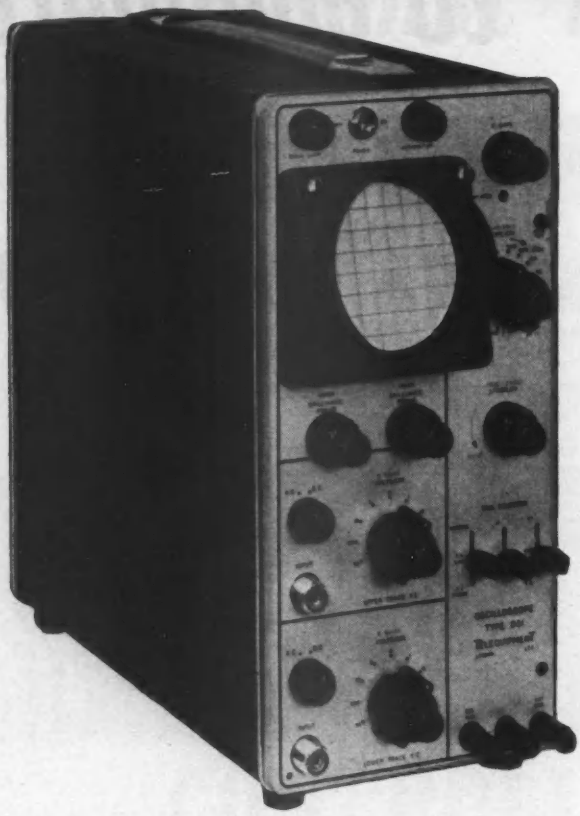
Illustrated is one of the HPOR series high-performance valves for use with all types of fuel oil

COMBUSTION SAFEGUARD AND SOLENOID VALVE DIVISION

ETHER LIMITED



D31

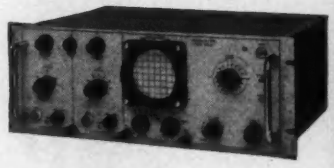


Potentialities per pound

Both per £ and per lb., each Serviscope* offers greater flexibility, accuracy and reliability than any oscilloscope of comparable specification. A radical reassessment of design and production techniques has enabled smaller, lighter, instruments with many improved features to be offered giving a far higher performance than their low price would suggest.

Weight: 26 lbs. **£95**

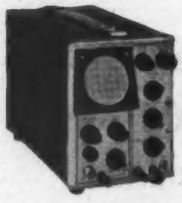
D31R



Electrically identical, but designed for mounting in standard 19½" racks.

D.31 double beam Serviscope*

D. C. amplifiers and slow speed time base (down to 5 sec/cm if necessary) are eminently suitable for servo work and similar applications. Fast rise time (.06 μ sec) and high writing speed (10 cm/μ sec at maximum expansion) are essential for any work dealing with fast pulses or TV waveforms. The unique triggering arrangements enable complex waveforms to be examined in detail with complete accuracy of synchronisation. At this moment the D.31 is in use in the diverse fields of computer development and servicing, radar equipment, telemetering applications, closed circuit and broadcast TV, automatic telephone equipment . . . and is proving itself ideally suited to laboratory work where an oscilloscope has, of necessity, to be somewhat of a Jack of all trades.



S31

S.31 single beam oscilloscope has the same specifications with a single beam display. The original, highly successful, 'Serviscope'.

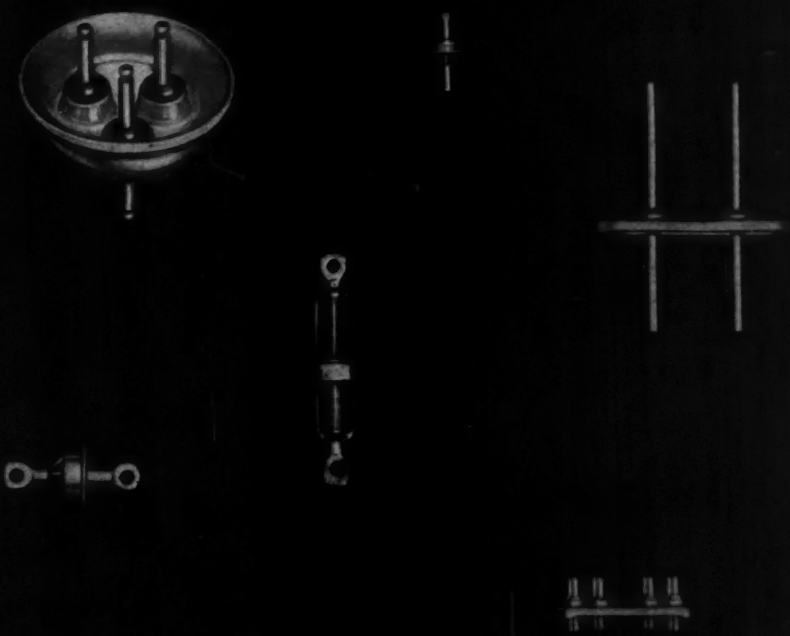
Weight: 16 lbs. **Price: £75**

* *'Serviscope' is the registered trade mark of Telequipment Ltd.*

TELEQUIPMENT

Telequipment Limited, 313 Chase Road, Southgate, London, N.14. Tel: Fox Lane 1166

STC hermetic seals



IN APPLICATIONS FROM TRANSISTORS TO REFRIGERATORS, **STC** HERMETIC SEALS HAVE PROVED THEIR PERFORMANCE AS HIGH GRADE COMPONENTS

From their wealth of experience and "know how" in so many fields, STC have evolved a range of seals to meet the most exacting standards of hermetic sealing. STC hermetic seals are available for many applications including:
Lead through insulators with flexible or solid terminations for transformers, relays etc.
Crystal base seals. Refrigerator seals.
End seals for cylindrical components.

Write for publication No. MK/153 which gives details of these and other STC Hermetic Seals.

STC COMPONENTS GROUP

60/8MK

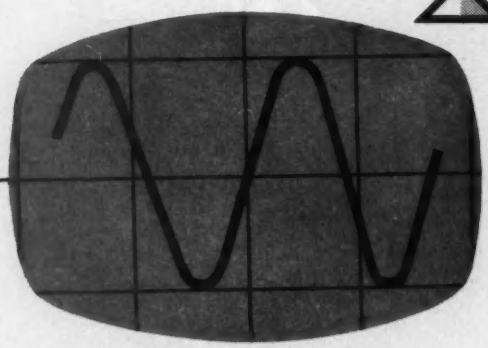
Standard Telephones and Cables Limited

Registered Office: Connaught House, Aldwych, London, W.C.2

TRANSISTOR DIVISION: FOOTSCRAY · SIDCUP · KENT

STAND No. B/2025/6/D INTERKAMA

STABILIZED SINUSOIDAL VOLTAGE



by Advance

the CVH RANGE

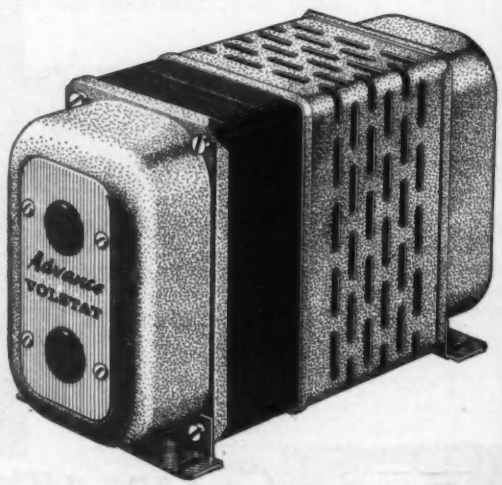
Advance constant voltage transformers are available in the CVH range with low harmonic distortion in the output waveform, ideal for use with precision equipment sensitive to power frequency harmonics, and also with all equipment requiring a constant voltage sinusoidal input.

In most applications the harmonic distortion present in the output waveform will not exceed 3%. Under the most unfavourable conditions this figure will not rise substantially above 5%. When used with a rectifier to provide a d.c. supply, the characteristics of the system are identical to the normal mains source and particularly close regulation of the output is obtained.

- CONTINUOUS AND AUTOMATIC STABILIZATION
- RAPID RESPONSE TIME
- CURRENT LIMITING CHARACTERISTIC
- COMPACT DESIGN
- NO MOVING PARTS
- NO ROUTINE MAINTENANCE

Type	I/P V Range	O/P V r.m.s.	Watts	p.f.	Nett Price in U.K.
CVH60A	190–260 50~	240	60	1.00	£10.10. 0
CVH125A	190–260 50~	240	125	1.00	£17. 0. 0
CVH420A	190–260 50~	240	420	1.00	£37. 0. 0
CVH750A	190–260 50~	240	750	1.00	£68. 0. 0
CVH1500A	190–260 50~	240	1500	1.00	£99. 0. 0
CVH3000A	190–260 50~	240	3000	1.00	£185. 0. 0
CVH6000A	190–260 50~	240	6000	1.00	£355. 0. 0

Full details in Folder G1 available on request

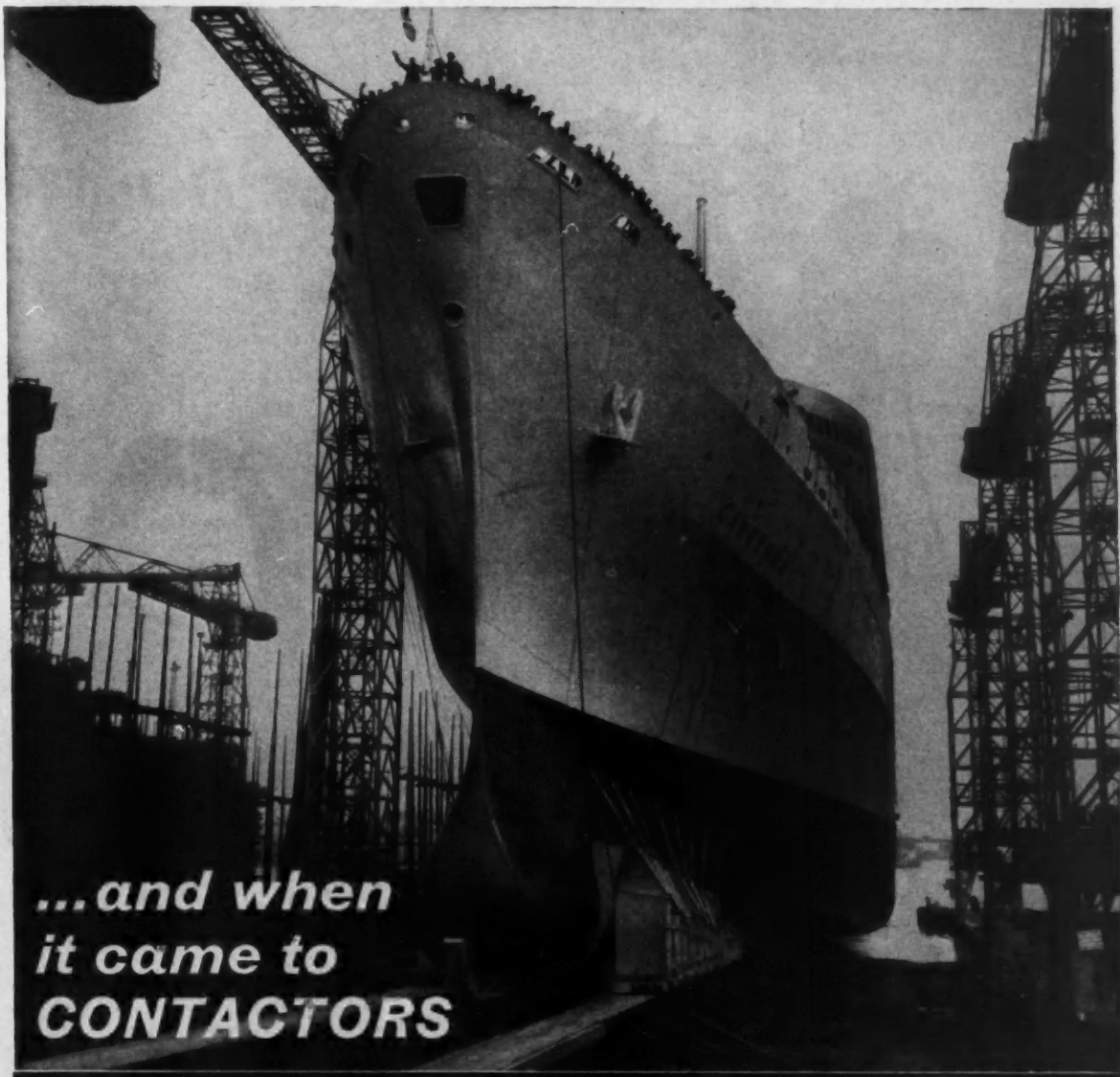


Advance COMPONENTS LIMITED

MAINS STABILIZATION DIVISION

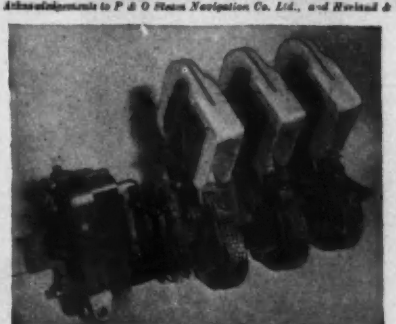
ROEBUCK ROAD • HAINAULT • ILFORD • ESSEX • TELEPHONE : HAINAULT 4444

IT/D8



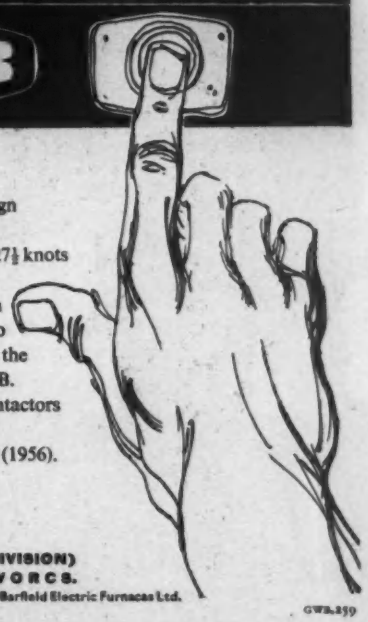
the choice was GWB

Ashore and shipments to P & O Steam Navigation Co. Ltd., and Harland & Wolff, Ltd. Photograph by Central Press Photos Ltd.



C.522 500 AMP rated T.P. Contactor, fitted one normally open and one normally closed auxiliary contacts, as supplied for use as remote controlled isolators for part of the equipment supplied from each masterboard of the S.S. Canberra.

Some very advanced thinking went into the design of the giant P & O Liner S.S. Canberra. With accommodation for 2,235 passengers, its speed of 27½ knots will cut the London-Sydney run by six days. Accuracy and efficiency were essential—right down to the smallest component—and when it came to the operation of remote controlled isolators from the masterboards the contactors specified were GWB. Containing many unique features, all GWB Contactors are type tested and approved to category A.4, Mechanical Duty Class III and IV to B.S.S.775 (1956). Full details of the complete range on request.



GWB **G.W.B. FURNACES LTD** (CONTROL GEAR DIVISION)
P.O. BOX 4 · DIBDALE WORKS · DUDLEY · WORCS.
Tel: Dudley 55433. Cables: Gibwildbar, Dudley. Associated with Gibbons Bros. Ltd. and Wild-Barfield Electric Furnaces Ltd.

GWB.259

What is your climate like?

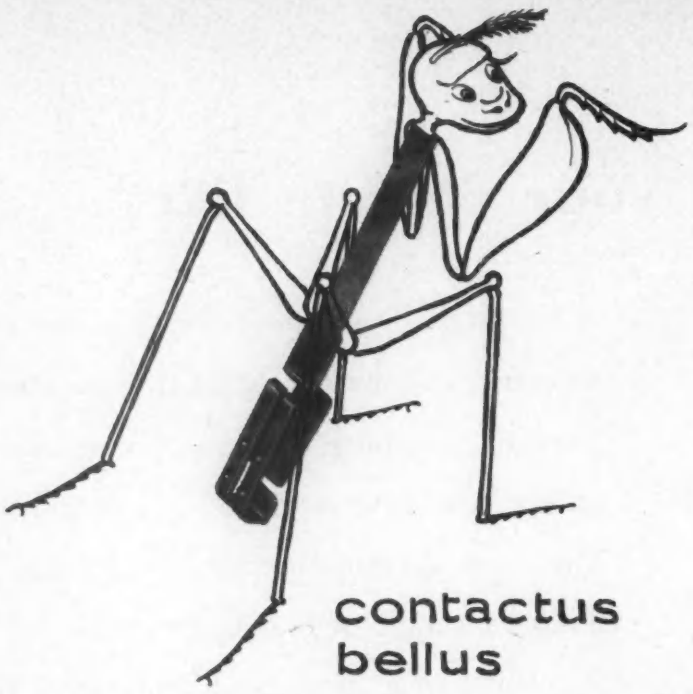
A recent enquiry (survey would be too grand a word for it) carried out by our editorial department found that an increasing number of readers were subscribing at the reduced Group* rate and taking a personal copy of *Control*. This, from our point of view, is splendid, for above everything we want to be thoroughly read.

But then a snag appeared. Reports from youngish readers frequently mentioned that although home reading was an improvement on snippets snatched from the office circulation copy during lunch, there were certain distractions to be reckoned with.

There is in our experience only one answer to this. One evening should be set firmly aside.

We are not seriously suggesting that Wednesday night should be *Control* night. But since up-to-date information is vital to career-building, an occasional strictly-reserved-for-reading session is surely justified.

*For details of the Group rate reduction tick and post the card opposite page 83.



contactus
bellus

You see here a creature who is not all he appears to be.
By himself this contact is but a touch,
with his mate to help him, he grips a circuit board,
seeming to have a strong vice.
In spite of this he will not mark or scratch the most delicate surfaces.
He will always be found,
with his mate,
in company with several other pairs,
formed into serried ranks and eagerly awaiting the arrival of the printed circuit.
Up to a short while ago
he and his kind had not been seen in this country,
but they are now at large in ever increasing numbers.
If you try to capture one you will find he will offer virtually no resistance.
Save yourself the trouble by contacting us,
when we shall be pleased to send you specimens.

Continental Connectors

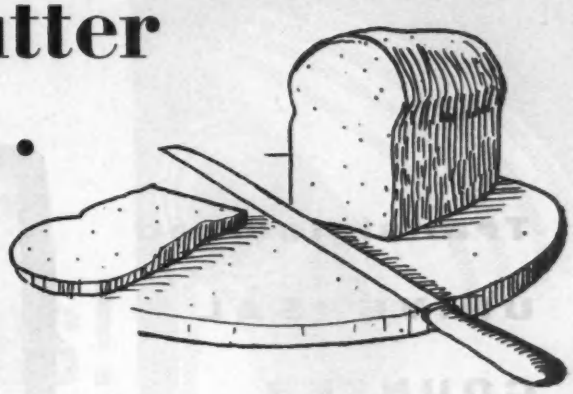
CONTINENTAL CONNECTOR DIVISION

ULTRA ELECTRONICS LIMITED

Industrial Estate, Long Drive, Greenford, Middlesex. Phone WAXlow 5721

Bread and butter business . . .

AN IMPORTANT SECTION OF THE ORGANISATION
MAINLY CONCERNED WITH MACHINED REPETITION WORK, IN A WIDE RANGE OF CONVENTIONAL AND NEW MATERIALS SERVING ALL SECTIONS OF INDUSTRY

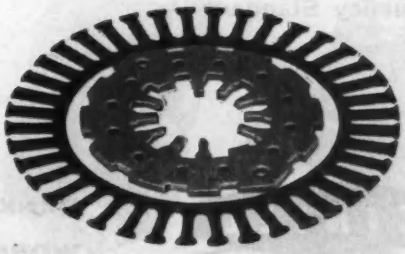


In addition to extensive development work in the fields of new materials and methods for the electrical and mechanical industries, The Delanco Company, has at the same time, to keep up the supply of a host of machined and turned parts, in a multiplicity of shapes and sizes, and in materials non-metallic.

Strength in relation to size, insulation properties, drilling and tapping propensities, all have to be provided for and in materials ranging from vulcanized fibre to glass fibre.

Washers, grommetts, studs, pins, bushes, spacers, rollers, non-metallic bolts and nuts, all are in demand. Take a typewriter, a washing machine, a clock, an adding machine, and a hundred and one other articles in daily use, and sure enough you will find some Delanco part doing whatever is required of it efficiently—thanks to the technical know-how allied to the latest machining techniques and years of experience.

Delivery and service second to none and a courteous and knowledgeable reception to your enquiry. You will want to know more about this service, so get in touch with DELANCO . . . NOW . . .



Anglo-American Vulcanized Fibre Co. Ltd

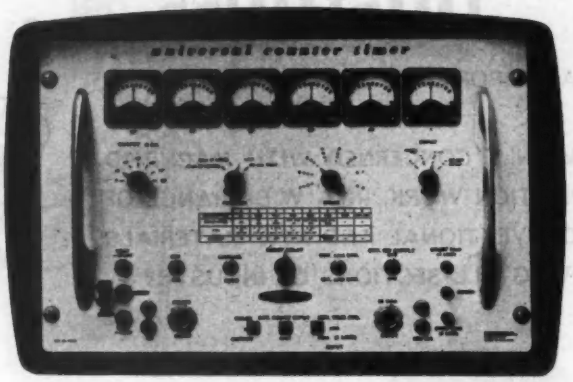
CAYTON WORKS · BATH STREET · LONDON · E.C.1

Telephone: **CLE 3271** *Grams:* **PROMPSERV, AVE, LONDON**

DELANCO WORKS — Delanco Electrical Insulation — LEONARD ST. E.C.2

Circle No 34 on reply card for further details

Transistorized UNIVERSAL COUNTER TIMER



Frequency Measurement

Random Counting

Frequency Division

Time Measurement

Frequency Standard

This fully transistorized portable equipment provides for a wide range of time and frequency measurement as well as facilities for counting, frequency division and the provision of standard frequencies. The facilities available are briefly listed below:

TIME/UNIT EVENT (1 LINE): For the measurement of the time interval between two occurrences in a continuously varying electrical function in the range 3μsec to 1sec. The time for 1, 10 or 100 such events can be measured.

TIME/UNIT EVENT (2 LINE): For time measurement in range 1μsec to 2777hrs. of any interval defined by a positive or negative going pulse in any combination.

EVENTS/UNIT TIME: For frequency measurement in range 30c/s to 1Mc/s over period of 0·001, 0·01, 0·1, 1 or 10secs. Crystal accuracy ±2 parts in 10^6/week. For mains or 12Vd.c. operation.

Full technical specification available on request.

CINTEL INSTRUMENT Division

RANK CINTEL LIMITED
WORSLEY BRIDGE ROAD · LONDON · SE26
HITHER GREEN 4600

Sales and Servicing Agents: Atkins, Robertson & Whiteford Ltd. Industrial Estate, Thornliebank, Glasgow;
McKellen Automation Ltd. 122 Seymour Grove, Old Trafford, Manchester 16; Hawnt & Co. Ltd. 112-114 Pritchett St., Birmingham 6.

on-off-
on-off-
on-off-

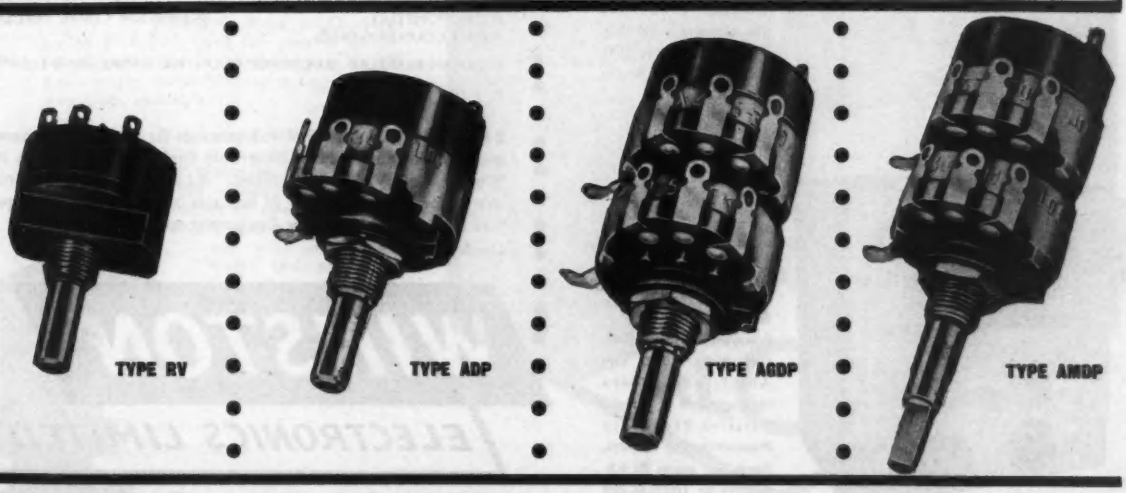
20,000 times!

Whether you export your radio, television or audio equipments to Scandinavia or not, SEMKO approval of components is important to you for its own sake. It guarantees a quite exceptional reliability and safety.

The Morganite Type 'V' switch is rated at 250 volts **2 amperes** and is therefore one of the highest rated SEMKO approved potentiometer switches of wholly British manufacture.

The SEMKO series of tests includes 20,000 operations at full load without a single permissible (even momentary!) mechanical or electrical failure. Compare that with the average 2,000 operations per year that a switch gets in actual use, and you see what the famous 'S' symbol on a Morganite switch means in terms of service! Fully complies with BSS415 too.

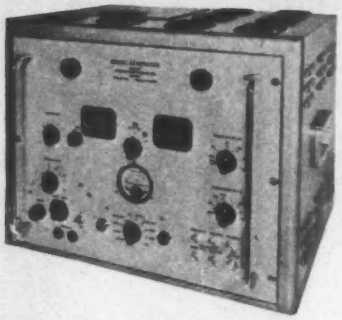
SEMKO approval for Morganite Potentiometer Switches



MORGANITE RESISTORS LTD.
BEDE TRADING ESTATE · JARROW · COUNTY DURHAM
TELEPHONE: JARROW 89-7771

J100A/344

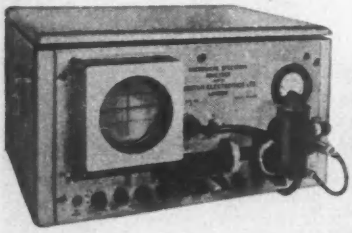
RADAR FREQUENCIES



L. BAND SIGNAL GENERATOR

Frequency Range 800-2100 Mc/s in one band; single-dial control directly calibrated to ± 1%

Frequency Stability warm-up drift < .2% ambient drift ≏ .003% I°C.



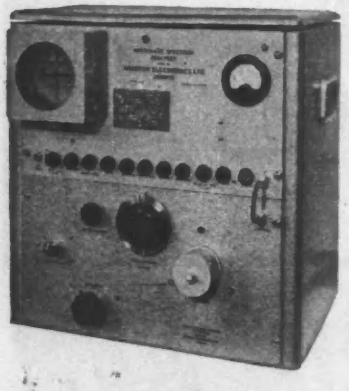
X-BAND SPECTRUM ANALYSER

Frequency coverage 8,600/10,000 Mc/s.

Absolute Frequency Measurement ± 1 Mc/s.

Relative Frequency Measurement ± 250 Kc/s.

Sensitivity minus 85db relative to 1mW at the input.



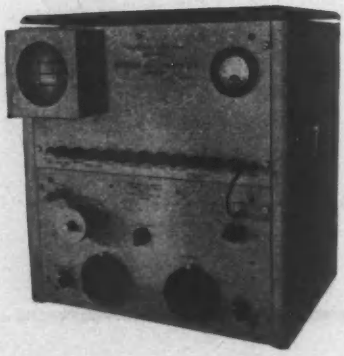
S-BAND SPECTRUM ANALYSER

Frequency Range 2640/3200 Mc/s.

Absolute Frequency Measurement ± 1.5 Mc/s.

Relative Frequency Measurement ± 250 Kc/s.

Sensitivity minus 85db relative to 1mW at the input.



L BAND SPECTRUM ANALYSER

Frequency Coverage 1000-1500 Mc/s, 20-30 cms

Absolute Frequency Measurement ± ½ Mc/s.

Relative Frequency Measurement ± 100 Kc/s.

Sensitivity minus 85 d.b. relative to 1mW at the input.

Winston Electronics offer these instruments to all those engaged in radar design and manufacture in X, S or L Band.

Winston Electronics are the authorised agents for Beckman/Berkeley frequency meters covering 10 c/s to 15,000 Mc/s.

IN ADDITION TO THE ITEMS FEATURED HERE THE WINSTON RANGE OF ELECTRONIC EQUIPMENT INCLUDES:—

CAPACITOR BOXES
RESISTOR BOXES
VALVE VOLTMETERS
TRANSIENT OSCILLOGRAPHS
BECKMAN HELICAL PRECISION POTENTIOMETERS
TURNS COUNTING DIALS
SHEET METAL WORK
STANDARD METAL CASES
SHOCKLEY DIODES
SEMI-DECADE OSCILLATORS
TEMPERATURE CONTROLLERS
TRANSISTOR CURVE TRACERS

BECKMAN/BERKELEY FREQUENCY COUNTING & MEASURING EQUIPMENT

SUB-CONTRACT Full sub-contract facilities for the development and manufacture of Electronic Equipment, and Sheet Metal Work. Coil Winding Facilities. A.I.D. and A.R.B. Approved. Write for full particulars of facilities available and catalogue of Instruments and Electronic Equipment to: Dept. C

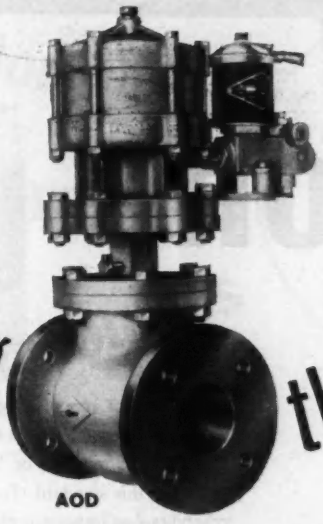
WINSTON ELECTRONICS LIMITED

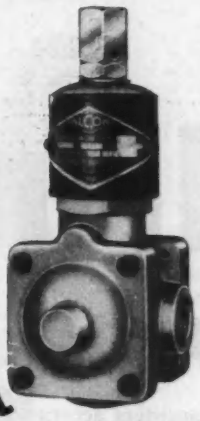
INSTRUMENTS—COMPONENTS—PRODUCTION FACILITIES

GOVETT AVENUE · SHEPPERTON · MIDDX. *Telephone:* Walton-on-Thames 26321/5 *Telegrams:* Winston, Shepperton

ACH

anything that flows


AOD


SPC 3

ACO

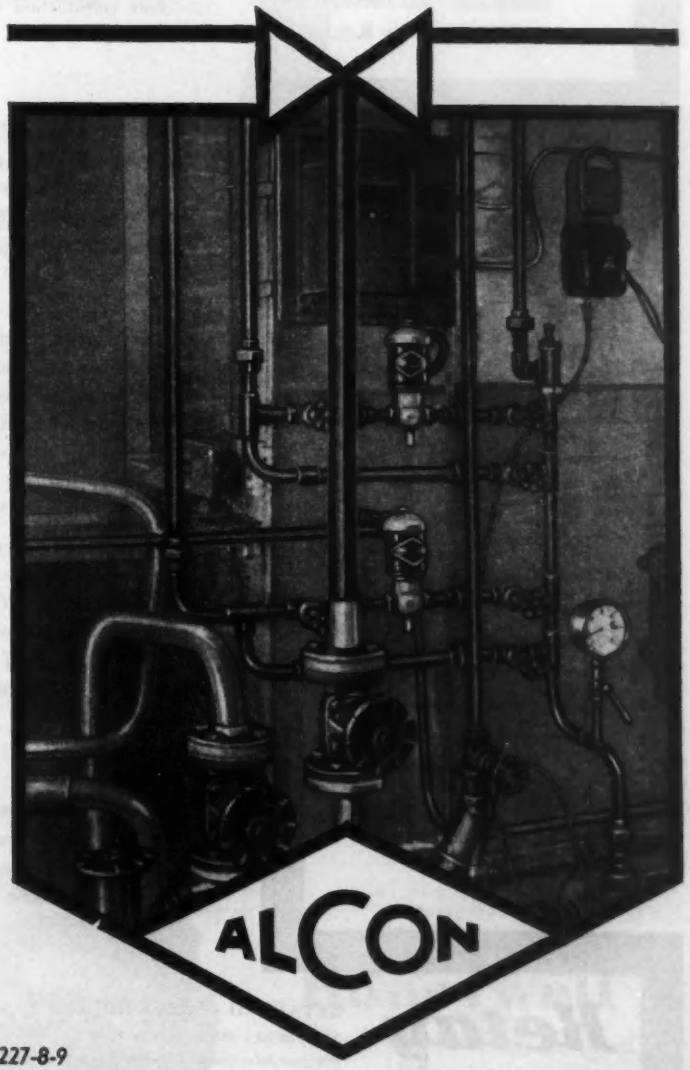
All Liquids and Gases can be positively controlled by an Alcon Solenoid or Air-Operated Valve. Sizes from $\frac{1}{8}$" B.S.P. to 8" Bore. Pressures up to 1,500 p.s.i. Temperatures up to 300°C. Body materials to suit all media including corrosive acids, with Standard, Weatherproof or Buxton Certified Flameproof Solenoid Housings. Glandless, Fluon Glands or Stainless Steel Bellows Glands.

AIR-OPERATED Type AOD —Heavy duty air operated units individually designed for control applications beyond capabilities of Solenoid types. For pressures up to 1,500 p.s.i. Sizes $\frac{1}{4}$" B.S.P.—8" Bore.

SPC.3—Three-way valves for electro-pneumatic control systems. Sizes up to $\frac{1}{2}$" B.S.P. for use with air up to 150 p.s.i.

MIDGET Type ACO—Sizes up to $\frac{3}{8}$" B.S.P., used for control of air, gases, water, oil at pressures up to 300 p.s.i. Single way—Reverse acting—Three-way types available.

ACH—Hand Reset type, closing automatically on current failure, for low and medium pressures. Sizes from $\frac{1}{4}$" B.S.P. to 6" Bore. Inexpensive, simple construction, reliable in operation. Also available type ACHL. Lever operated for use with steam, hot water and pre-heated fuel oils.



'Phone : SUTton Coldfield 5227-8-9

ALEXANDER CONTROLS LTD., REDDICAP HILL, SUTTON COLDFIELD, WARWICKSHIRE

A MEMBER OF THE CONCENTRIC GROUP OF COMPANIES

all in one

Consistent accuracy, small size, mechanical ruggedness and an efficiency unimpaired by extreme conditions—all these, in every synchro made by Ketay.

✳ As a result of recent design developments, the latest Ketay synchros are able to detect shaft movement of as little as three minutes, or 1/7,200 of a revolution! In achieving this standard of accuracy—and an unfailing reliability—an important part is played by the through-bore construction which is a vital characteristic of these synchros.

✳ They are small and light enough for use in many critical applications where size and weight must be minimal. The smallest in the current range—which covers sizes 11 to 23, with size 08 soon to be in production—has an outside diameter of just 1.1″ and weighs only 4.0 ounces.

✳ This valuable miniaturisation involves no sacrifice of mechanical ruggedness—with stainless steel housing and encapsulated windings, Ketay synchros will perform efficiently and consistently under most severe conditions of impact or vibration.

✳ They also maintain the same high level of performance in extreme temperatures. Generally, the operating range is −55°C to +85°C, but recent progress has enabled even these figures to be bettered; a new Ketay series of synchros capable of working at 125°C is already available and developments are in hand to improve this figure to 200°C.

✳ Ketay synchros have an outstandingly high resistance to moisture and other climatic conditions; this is afforded by stainless steel housings, shafts and bearings, hermetically sealed windings and other design features.

Every one of these units embodies the highly specialised knowledge of Ketay engineers who are continually at work on environmental and accuracy problems connected with servo components and systems. Their very considerable experience and skills, backed by superior development facilities, are available as a service of which all plant designers and engineers are invited to make full use.

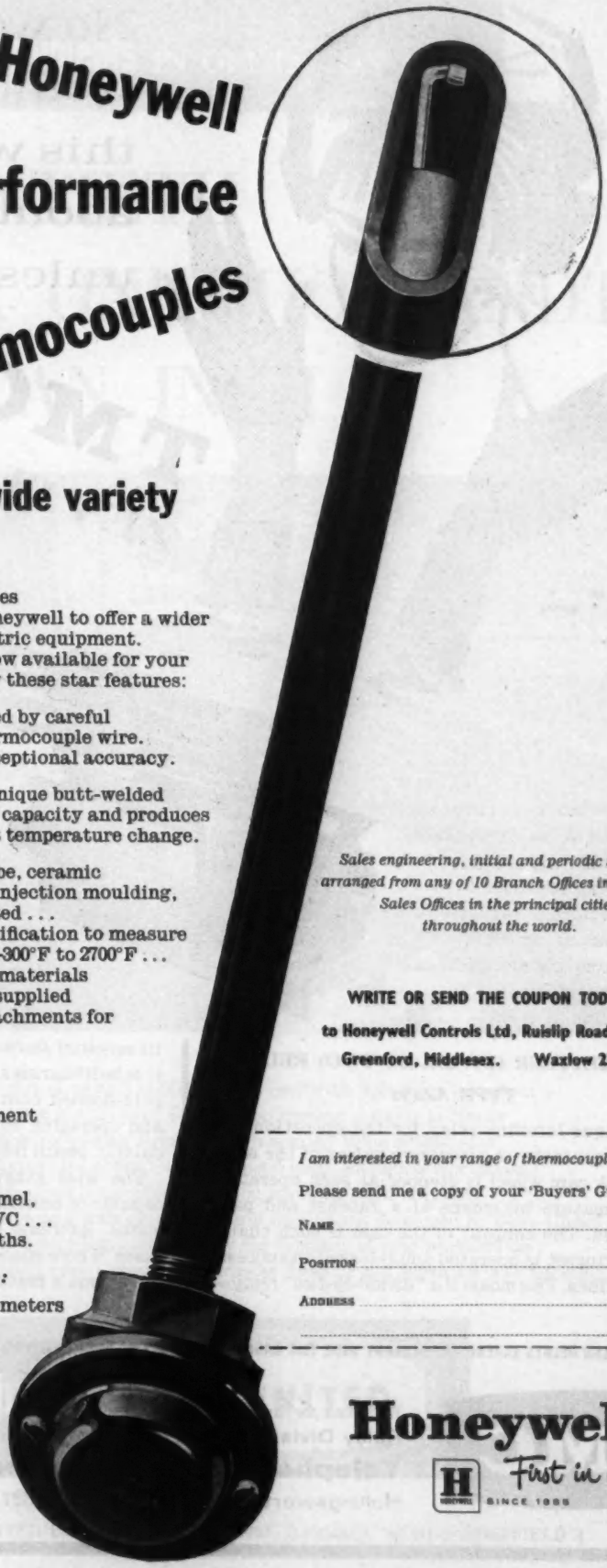
Ketay

KETAY LTD · EDDES HOUSE · EASTERN AVENUE WEST · ROMFORD · ESSEX
TELEPHONE: SEVEN KINGS 6050
Overseas Sales Organisation: Plessey International Limited · Ilford · Essex Tel: Ilford 3040

K9

Honeywell top performance thermocouples

now appearing in wide variety



Improved production facilities now make it possible for Honeywell to offer a wider variety of first class pyrometric equipment. Thermocouple assemblies now available for your every need and purpose show these star features:

'Topmost' Accuracy . . . achieved by careful testing and matching of thermocouple wire. Premium grade wires for exceptional accuracy.

'Topmost' Response Speed . . . unique butt-welded hot junction minimises heat capacity and produces rapid response from smallest temperature change.

'Topmost' Variety . . . metal tube, ceramic tube . . . exposed tip, angle, injection moulding, glass feeder, mineral insulated . . . thermocouples of every specification to measure temperature in ranges from -300°F to 2700°F . . . thermocouples with special materials for use up to 4000°F. All are supplied with suitable mounting attachments for individual needs.

'Topmost' Tolerances . . . for compensating leadwires, ensuring accurate measurement at low cost. Leadwires are available with a wide range of insulating materials, including asbestos over enamel, polythene or plastic over PVC . . . flexible rubber . . . lead sheaths.

. . . and to complete the range:

Radiamatic Radiation Pyrometers (for temperatures between 125°F and 7000°F) and Resistance Bulb Assemblies (for temperatures between -200°C and 500°C).

Sales engineering, initial and periodic service, arranged from any of 10 Branch Offices in the U.K. Sales Offices in the principal cities throughout the world.

WRITE OR SEND THE COUPON TODAY

to Honeywell Controls Ltd, Ruislip Road East, Greenford, Middlesex. Waxlow 2333

I am interested in your range of thermocouples

Please send me a copy of your 'Buyers' Guide'

NAME .....

POSITION .....

ADDRESS .....

..... C

Honeywell

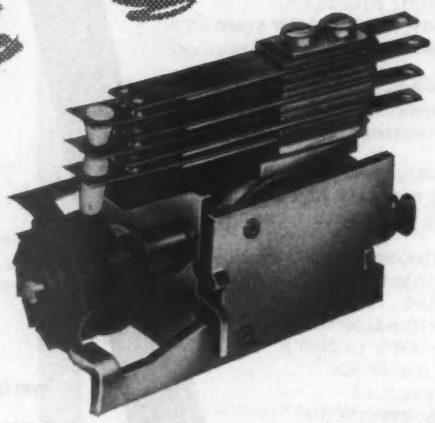
First in Control

SINCE 1885

Circle No 40 on reply card for further details

No woman would act this way about a Relay unless...

It's a **TMC ZETTLER RELAY** and she's an electrical engineer



Well . . . we can't vouch for the woman. But we can for the Relay. It's one of the wide range commanding attention by offering decided advantages in every aspect of industrial control involving electrical and electronic equipment.
To be specific, it is the—

TMC ZETTLER (DIVIDE-BY-TWO) RELAY

TYPE AZ170

. . . a unique latching relay for the operation and release of contacts on successive pulses of the same polarity. A cam wheel is stepped at each operation of the armature by means of a ratchet and pawl mechanism. The contour of the cam is such that a simple springset is operated and released on successive operations. *This makes it a "divide-by-two" relay—its essential feature.* The armature is hinged on captive ball bearings for maximum reliability. Twinned, gold-flashed contacts have up to two change-overs and operating coils up to 110 volts D.C. It is particularly useful for remote control switching.

The wide range of TMC ZETTLER RELAYS is capable of handling power from microwatts to kilowatts. Extreme compactness is achieved in most cases. Where space is limited, their choice is destined to become a matter of course.

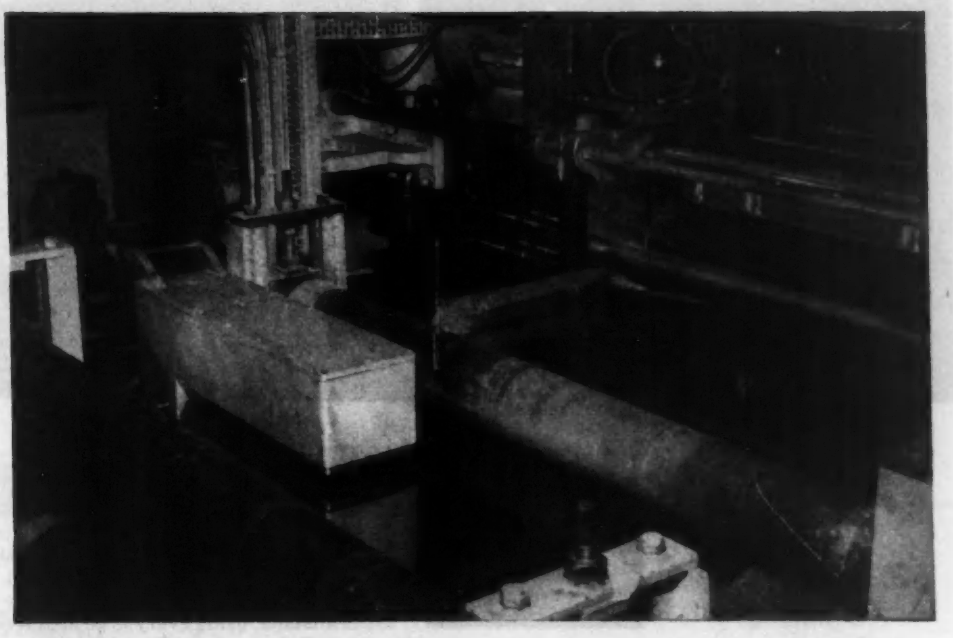
TMC ZETTLER RELAYS EXTEND THE ALREADY WIDE TMC RANGE AND MAKE TMC BEST EQUIPPED TO MEET YOUR RELAY REQUIREMENTS

TMC

Write now for further information.
Relay Division C
Telephone Manufacturing Company Limited
Hollingsworth Works, London, SE21. Telephone: GIPsy Hill 2211

DAVY-UNITED **instruments** IN OPERATION

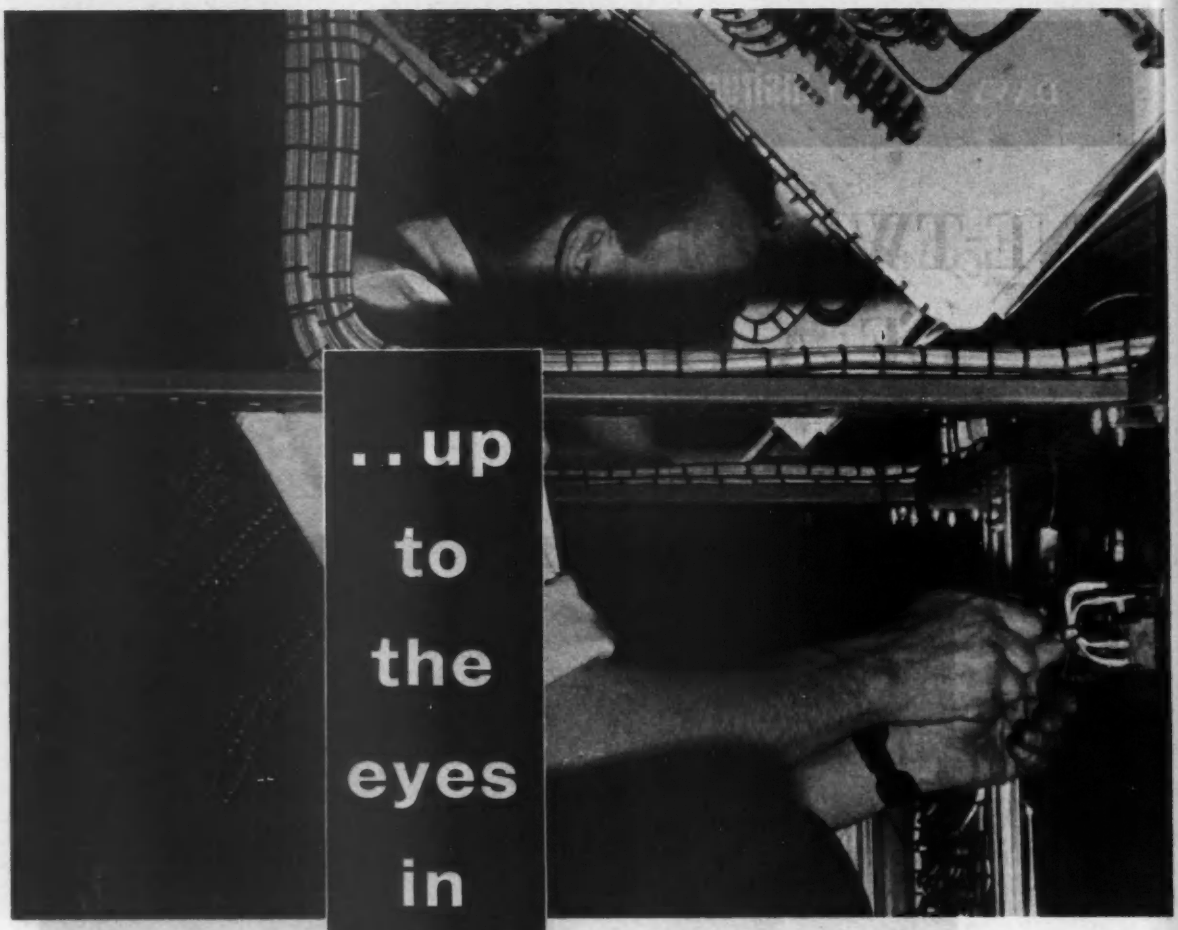
ONE-TWENTIETH OF A ONE-THOUSANDTH PART OF AN INCH



A twentieth of a one-thousandth part of an inch (.00005" if you prefer the figures), is just about a fortieth of the thickness of the average human hair. Today, measurement to limits as fine as this can be made on the thickness of rolled steel strip while it is actually being processed—continuously and without any necessity for contact with the metal itself. Radiation type gauges, using radio-active isotopes, capable of such consistent precision under the hard operating conditions of a steelworks, are amongst a wide range of control instruments developed by Davy-United. They include A.G.C., a system for controlling automatically the thickness of strip produced on both hot and cold mills, which rolling plants in such countries as America and Japan are now adopting.

instrumentation by DAVY-UNITED

373/DU DAVY AND UNITED INSTRUMENTS LIMITED, DARNALL WORKS, SHEFFIELD 9



..up to the eyes in it!

Data amplifiers
Automatic typewriter system
Pressure & Load transducers
Torque Measurement
Electronic Design Service
Counter Timers

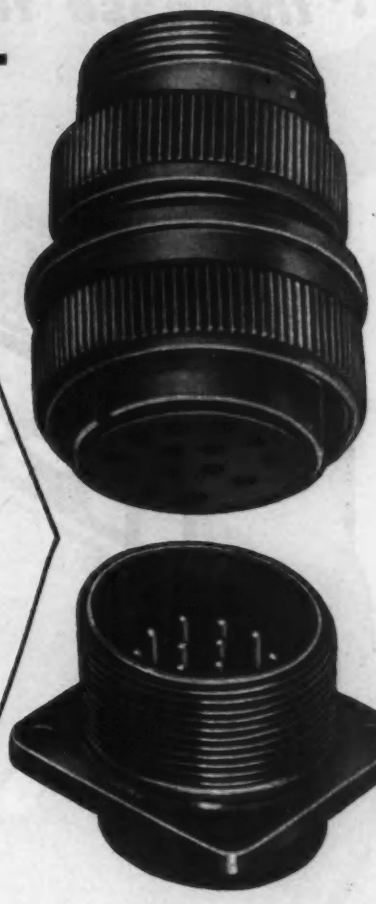
It takes a brilliant mind and an orderly one to design and develop new installations and electronic techniques appropriate to the problems of the 60's. The skilful manufacture to these designs by the craftsmen, using every type of aid, is equally important. Based on the experience of the Black Knight Research Vehicle Programme and a wide range of commercial contracts, the standard of neatness and finish, essential to long trouble-free life is a particular feature of Saunders-Roe electronic apparatus. If you have an engineering problem, we may be able to offer you a solution, based upon the latest electronics engineering techniques.

SAUNDERS — ROE

A member of the Westland group of companies

ELECTRONICS DIVISION
OSBORNE WORKS EAST COWES ISLE OF WIGHT
Telephone :- Cowes 2211

Thorn ELECTRICAL CONNECTORS

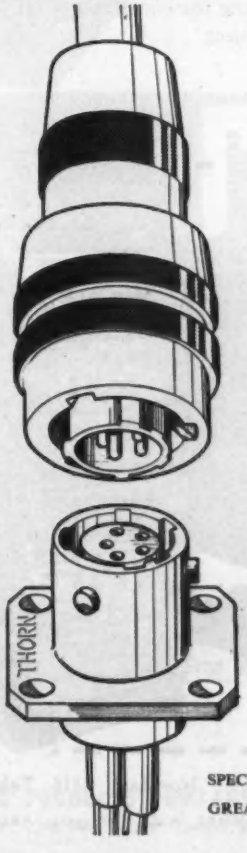


THORN AN SERIES

The Thorn AN series of electrical connectors includes solid shell/ general purpose, pressurised and environmental resisting ranges. By specifying Thorn, designers are assured of a *genuine* AN connector for their installations . . . a connector designed strictly to the current MIL specifications.

Note these outstanding design and operating features.

- *Die-cast aluminium alloy shells cadmium plated for corrosion resistance.*
- *Resilient insert eliminates shrinkage problems and ensures superior electrical performance through high arc resistance, high dielectric strength and low moisture absorption.*
- *Thorn grommet increases flash-over and creepage distances, excludes dirt and moisture.*
- *Pressurised, water-tight, radio-quiet assembly.*
- *Maximum performance, minimum weight.*



THORN PYGMY PT SERIES

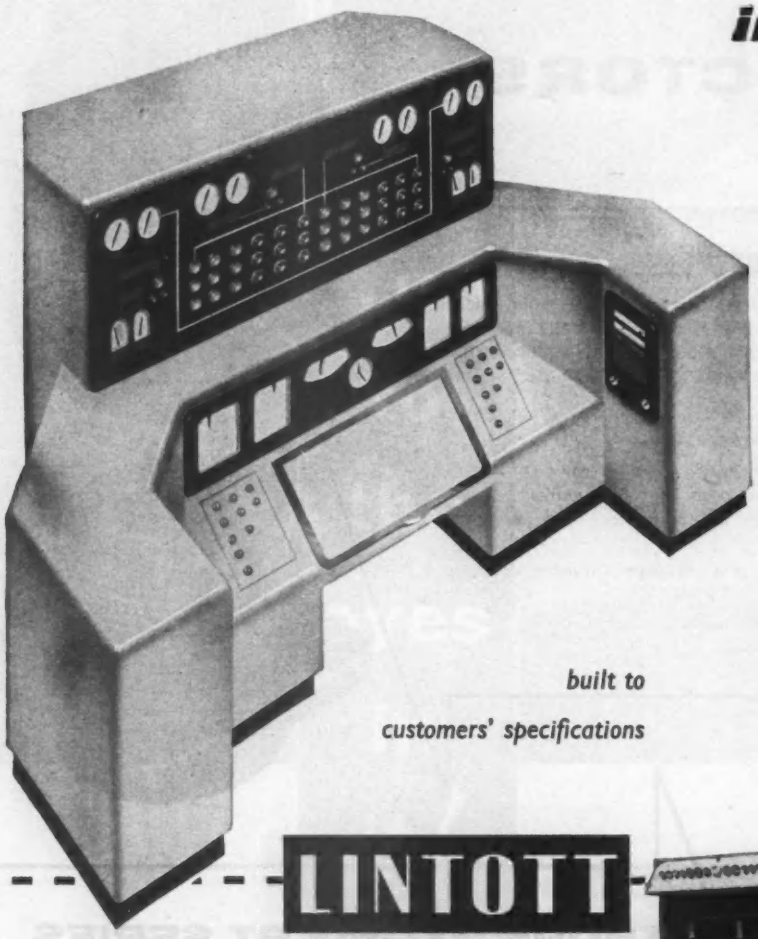
A new range of miniature connectors that satisfy the requirements of R.C.S. 321 (Category 40/100, class H.2 sealed items). Thorn Pygmy connectors are ideal for applications where space is limited and weight represents a critical factor of the installation.

- *Heavy gold plating over silver on all contacts.*
- *Performance unimpaired over a continuous temperature range from —40° to +100°C.*
- *Visual and audible inspection of coupling—perfect for "blind" locations.*
- *Three-point bayonet lock; perfect axial alignment of mating parts at all times.*
- *Five-key polarisation—positive protection against mis-mating or cross plugging.*
- *Miniaturised—light weight—compact.*

SPECIAL PRODUCTS DIVISION (incorporating Components and Connectors) THORN ELECTRICAL INDUSTRIES LTD
GREAT CAMBRIDGE ROAD ENFIELD MIDDLESEX TEL: ENFIELD 5353

* the case for perfect housing

in electronics



built to customers' specifications

FOR CONTROL

Desks and Panels

Lintott fabrication serves the electronic and nucleonic industries with Control Desks and Panels that enhance the operating scheme. Working in close collaboration with designers, Lintott produce units for all forms of process control, burner control, nuclear control, etc. This includes sheet metal work, surface finishing, flow diagram mounting and installation of instruments and switchgear. Perfect housing helps to sell your equipment. Let Lintott quote for construction on your next project.

LINTOTT

FOR EQUIPMENT...

a flexible system of cabinets

Lin-cabinets provide a standard and yet completely flexible system for housing electronic and electro-mechanical equipment. They are designed to accommodate any arrangement of components and any combination of chassis. Each unit is self-contained, with built-in cooling or heating facilities, and are suitable for slight pressurisation. The three standard drawers of 8″, 12″ and 16″ can be used in any combination to give a total height of 52″ and any number of cabinets can be interlinked. Lin-cabinets are K114 approved for the three Services and lend themselves to many applications. Plan your equipment layout with Lin-cabinets in mind and enjoy low installation costs, low maintenance costs, with maximum efficiency.

Data Sheet LC. No. 1.

AYLING INDUSTRIES GROUP

H. & E. LINTOTT LTD., Horsham, Sussex. *Telephone:* Horsham 3316 Telex 8746

and at the AYLING INDUSTRIES GROUP *London Office:* GRAND BUILDINGS, TRAFALGAR SQUARE, W.C.2. *Telephone:* TRAfalgar 6282

The New BURGESS V-4

* No larger than the average cuff-link
* New mechanism has mechanical life of at least 10 million operations
* Three types of solder terminals available
* Comprehensive range of auxiliary actuators

BURGESS MICRO SWITCHES

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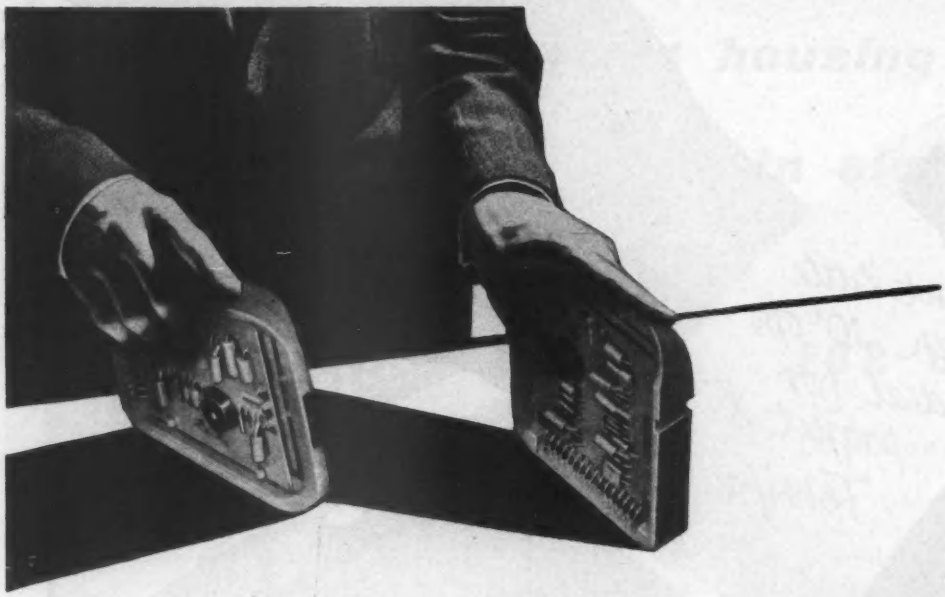

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Telemetry
Data Handling and
Data Logging

...**that** these systems can be extended or modified to meet requirements

...**that** easy maintenance, minimum equipment and reliability are inherent features provided by these units.

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data processing

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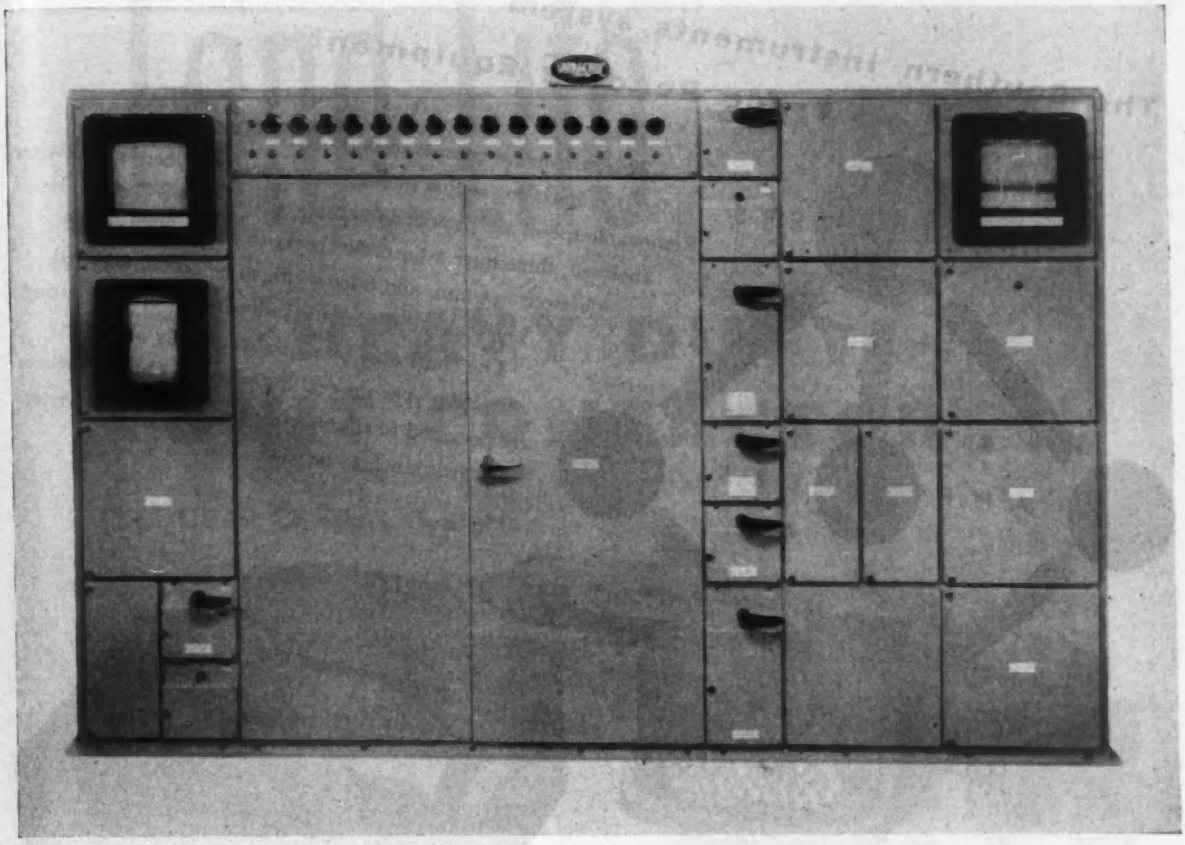
Marconi House, Strand, London, W.C.2
Data Processing and Control Systems Division,
Kidsgrove, Stoke-on-Trent, Staffs.
Telephone: Kidsgrove 2141/3

EDC. 27



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LOW COST
WIDE VERSATILITY

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Advac

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by Advance

The Advance Advac has all the qualities required in a first-class laboratory tool. An extremely sensitive a.c. valve voltmeter, it also functions as a wide range amplifier or as a null detector and indicator. Compact and of robust construction, the Advac is an outstanding product of Advance skill and experience in the world of instrumentation.

EXTREME SENSITIVITY	**accurate down to 100 μV**
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WIDE FREQUENCY RANGE	**15 c/s to 4·5 Mc/s**
AMPLIFIER RANGE	**10 c/s to 10 Mc/s**
AMPLIFIER GAIN	**60 dB in 10 dB steps**
AMPLIFIER OUTPUT	**1 V max**

nett price in U.K. **£50**

including very low capacity screened leads and probe

SIZE
4¼" × 7½" × 6¼"
WEIGHT
7 lb

TYPE
VM77

Leaflet No. GF101 available on request

INTERKAMA

STAND No.
B/2025/6/D

Advance COMPONENTS LIMITED

INSTRUMENTS DIVISION

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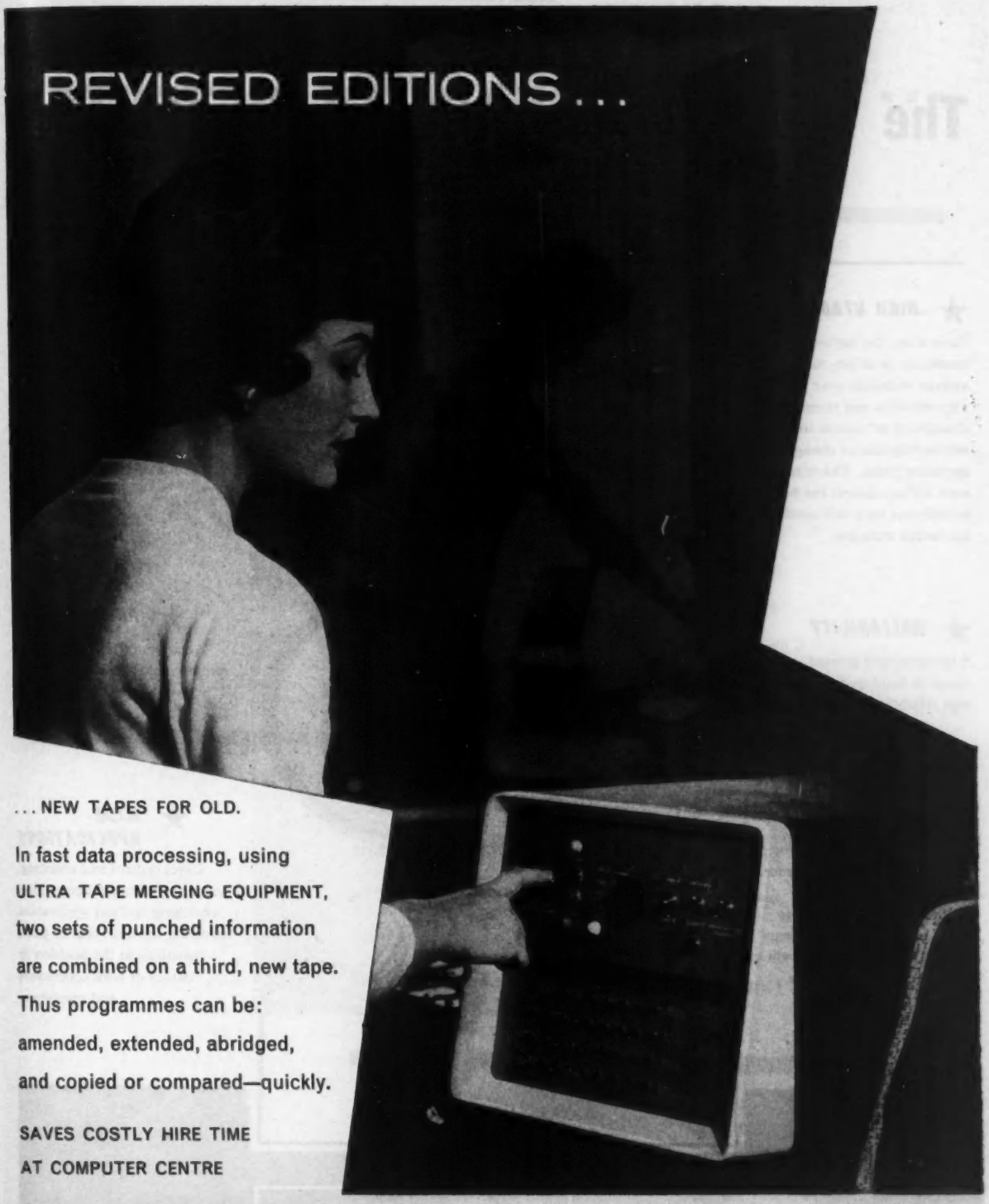
IT/Ea

REVISED EDITIONS...



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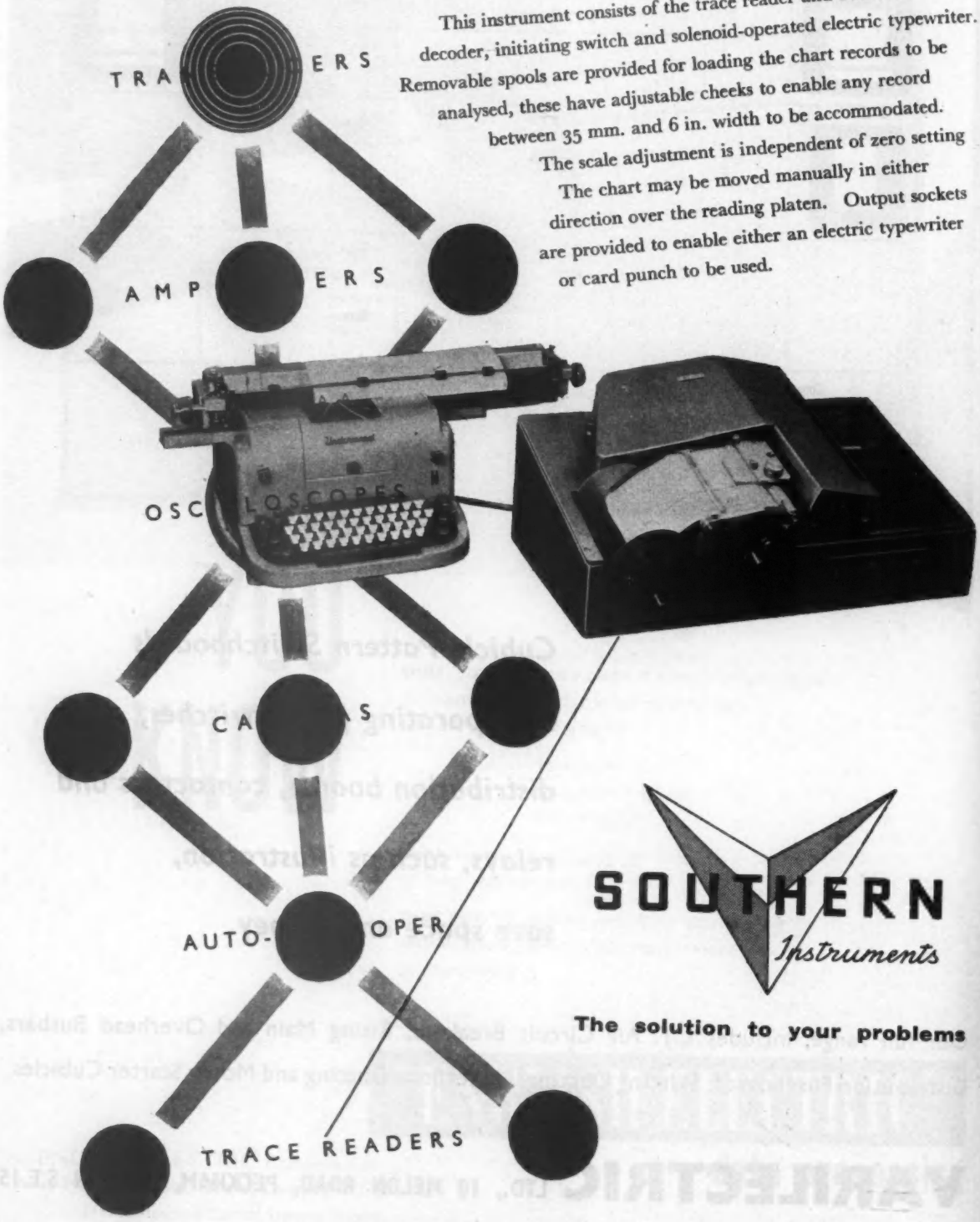
RADIO AND RADAR SYSTEMS · AIRCRAFT ENGINE CONTROLS & INTERCOMM · DATA PROCESSING EQUIPMENT

The Southern Instruments system

Trace Reading Equipment



This instrument consists of the trace reader and built-in decoder, initiating switch and solenoid-operated electric typewriter. Removable spools are provided for loading the chart records to be analysed, these have adjustable cheeks to enable any record between 35 mm. and 6 in. width to be accommodated. The scale adjustment is independent of zero setting The chart may be moved manually in either direction over the reading platen. Output sockets are provided to enable either an electric typewriter or card punch to be used.

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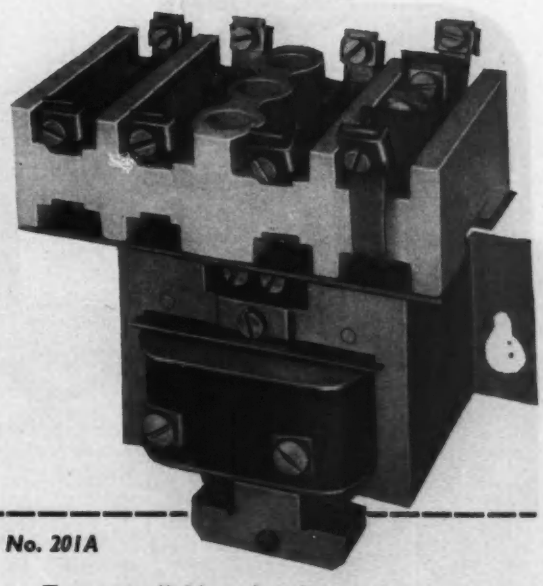
- Double air break
- No wearing parts

The standard unit is fully tropicalised making it suitable for use throughout the world.

Up to 550V AC. at 25, 50 & 60 cycles. 15 amp thermal rating to BSS 775—1956. CSA approved.



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3 pole—with one normally open and one normally closed auxiliary.

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HIGH SENSITIVITY
LOW COST
WIDE VERSATILITY

with the

Advac

A.C. VALVE VOLTMETER

by Advance

The Advance Advac has all the qualities required in a first-class laboratory tool. An extremely sensitive a.c. valve voltmeter, it also functions as a wide range amplifier or as a null detector and indicator. Compact and of robust construction, the Advac is an outstanding product of Advance skill and experience in the world of instrumentation.

EXTREME SENSITIVITY	**accurate down to 100 μV**
WIDE VOLTAGE RANGE	**1 mV to 300 V F.S.D.**
WIDE FREQUENCY RANGE	**15 c/s to 4·5 Mc/s**
AMPLIFIER RANGE	**10 c/s to 10 Mc/s**
AMPLIFIER GAIN	**60 dB in 10 dB steps**
AMPLIFIER OUTPUT	**1 V max**

nett price in U.K. **£50**

including very low capacity screened leads and probe

SIZE
4¼" × 7½" × 6¼"
WEIGHT
7 lb

TYPE
VM77

Leaflet No. GF101 available on request

INTERKAMA

STAND No.
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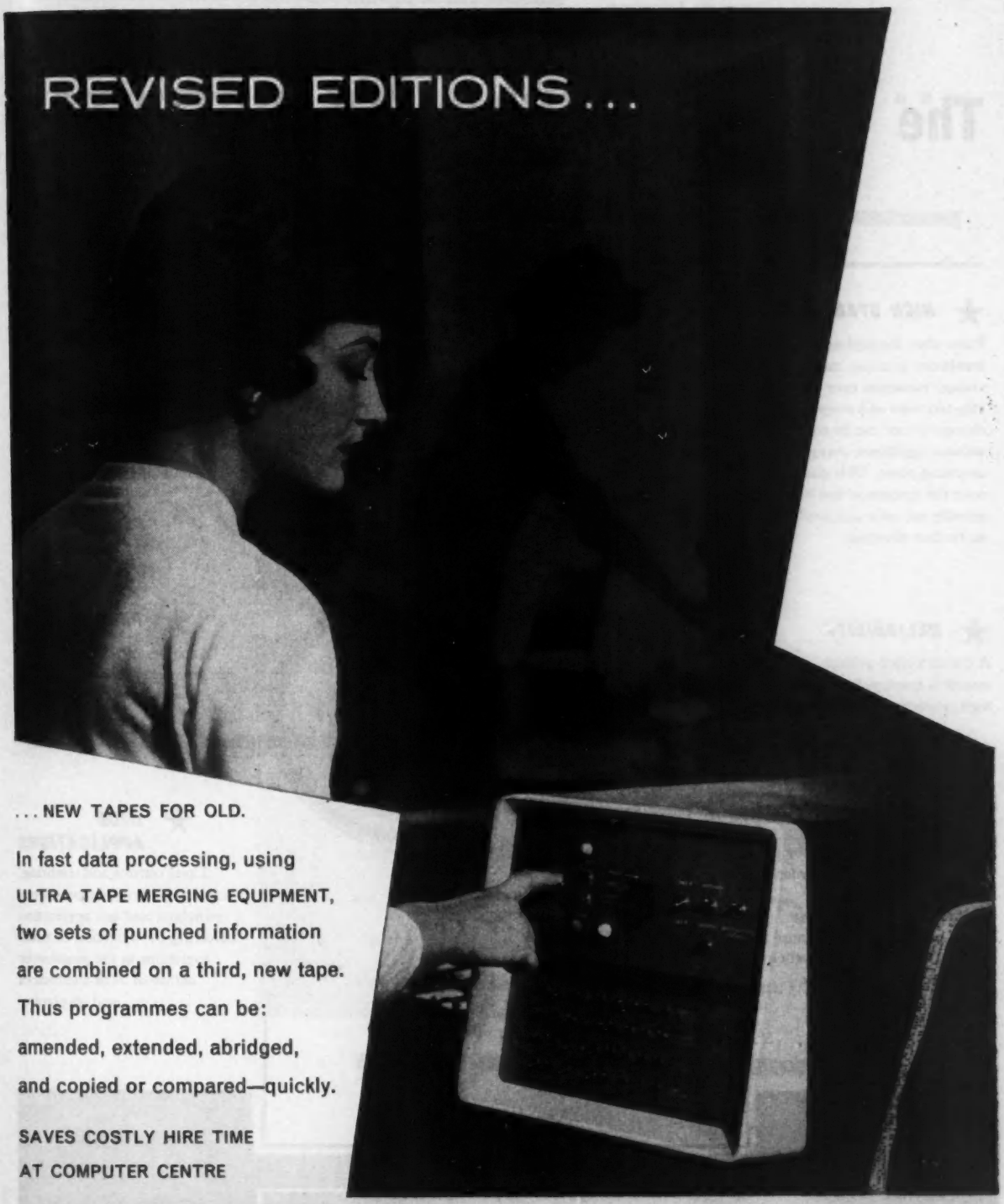

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RADIO AND RADAR SYSTEMS · AIRCRAFT ENGINE CONTROLS & INTERCOMM · DATA PROCESSING EQUIPMENT

Nothing touches . . .

The AIRMEC PROXIMITY DETECTOR

TYPE N266

The Proximity Detector Type N266 is a capacity-operated switch with a wide range of application in the fields of measurement and control. It is operated by any physical variable appearing as a small movement. The equipment consists of a control unit housed in a robust cast light-alloy industrial case, sealed against the ingress of dust and moisture, together with a sensing probe. The probe which contains no electronic components and is therefore unaffected by heat or rough treatment, may be fitted with a cover for use in liquids or corrosive atmospheres.

★ ***HIGH STABILITY***

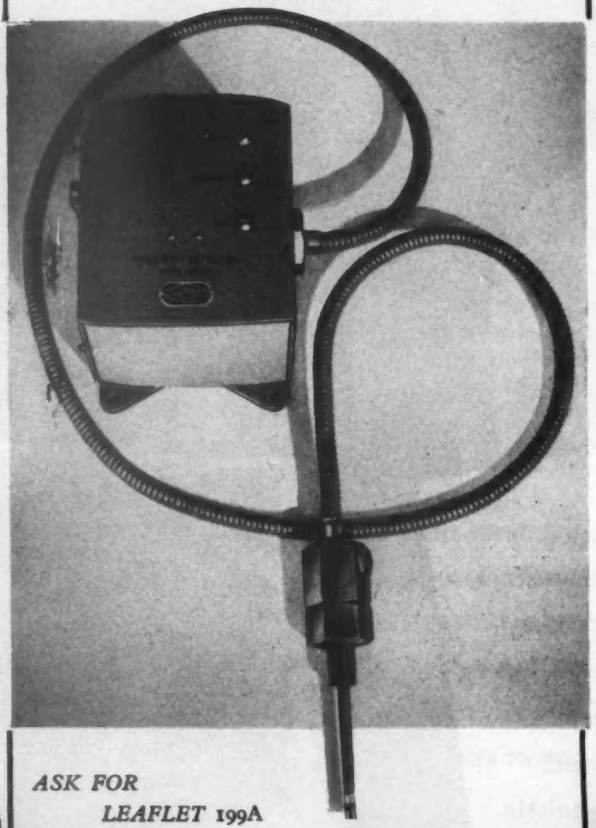
Even when the highest sensitivity is in use, mains voltage variations over the range 180-260 volts and temperature changes of 20° can be tolerated without significant change of operating point. This means that once the equipment has been initially set up it will need no further attention.

★ ***RELIABILITY***

A transistorised printed circuit is employed for its high reliability.

★ ***MAINS OR BATTERY***

Either a mains power unit or a battery unit is fitted to order. Under maximum current conditions the battery life is excess of 200 hours, at 4 hours per day, but in many applications the battery life may well be extended to the shelf life.



ASK FOR LEAFLET 199A

★ ***EXCEPTIONAL SENSITIVITY***

Its sensitivity is such that it will detect a capacity change of 0.05 micro-microfarad, representing a movement of the order of tenths of thousands of an inch under suitable conditions.

★ ***PROBES***

A variety of probes (fixed or remote) are available for a wide range of applications.

★ ***WIDE APPLICATIONS***

Level control and counting, sorting, grading, gauging, limit switching and any application involving the detection of small variations in the position or nature of both conductors and insulators.

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without considering the Stantec-Computing System incorporating an unusually versatile, medium-sized electronic digital computer. Designed specifically for commerce and industry, its wide variety of routines are being already applied in fields as far apart as food manufacturing, stock control and basic aeronautical research; solving complex calculations and problems in a fraction of the normal working time.

Capital outlay on a Stantec System is low and is speedily offset by the considerable economies it makes in time, labour and operating costs.

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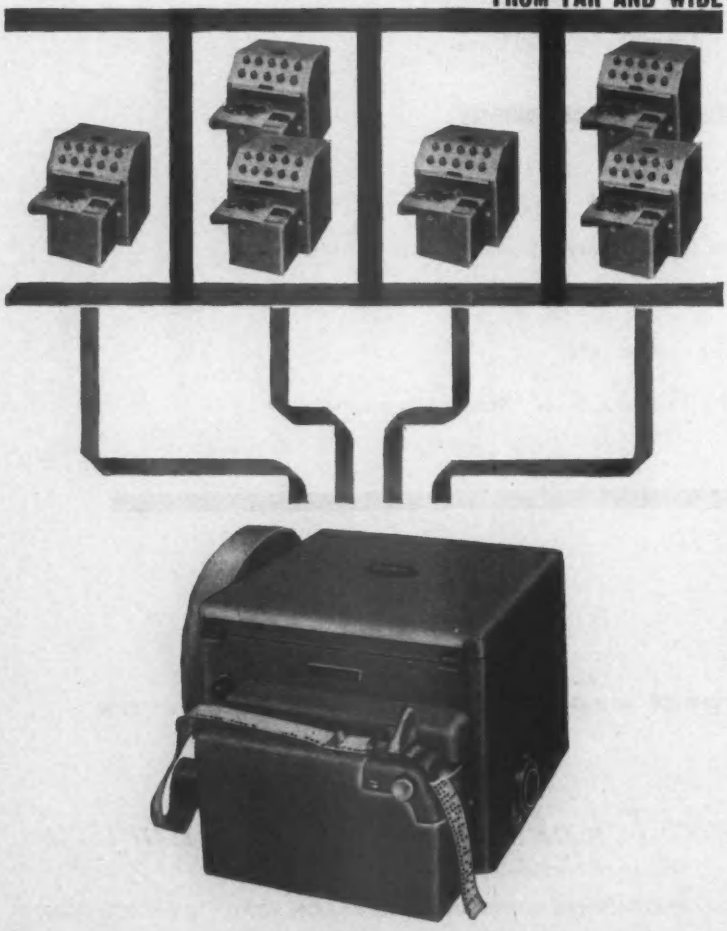
FRIDEN COLLECTADATA

TAPE OPERATED EQUIPMENT

COLLECTS THE FACTS

FROM FAR AND WIDE



This latest range of FRIDEN IDP equipment will collect data from any number of points and punches it onto tape at a data processing centre. The FRIDEN 8 channel tape code is used throughout the system, which consists of two basic units; the *transmitter*, which can be designed to read either tape and edge punched cards, or tabulating cards, and is connected by common cable to the *receiver;* which punches tape and may be fitted with a Time Code Emitter to record on the tape the time each transmission is received.

The great advantages of this system are its speed, simplicity, and freedom from those inevitable transcription errors of manual recording and collection of data. Amongst its other important features are: provision at the transmitter for identification of each type of transmission; checking at the receiver for odd parity of each code as it is punched, which results in automatic operation of an Error Indicator on the transmitter calling for repeat transmission; a Line Busy Indicator on the transmitter which suspends operation, and automatically allows transmission when the line is clear; transmission will not commence should a data card be wrongly inserted; a special code at the end of a card 'holds' the line clear for any further transmissions required; up to 18 digits of variable data may be set up on the transmitter itself, to be sent whenever a transfer code is read. The scope of the FRIDEN COLLECTADATA is enormous, and any attempt to detail its applications here would be quite impossible. Three of the most significant are Production Control, Time Recording and Stock Control, but anyone conversant with the executive and administrative operations of commerce and industry will envisage many other potential fields of use.

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BUSINESS MACHINES LTD

BULMERS have now attained a leading position in this sphere of IDP, and their team of specialists is at your disposal, for general discussion or to advise on any specific problem. Please write to arrange an appointment or to obtain full details of 'COLLECTADATA' and other FRIDEN IDP equipment;

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DTV A27

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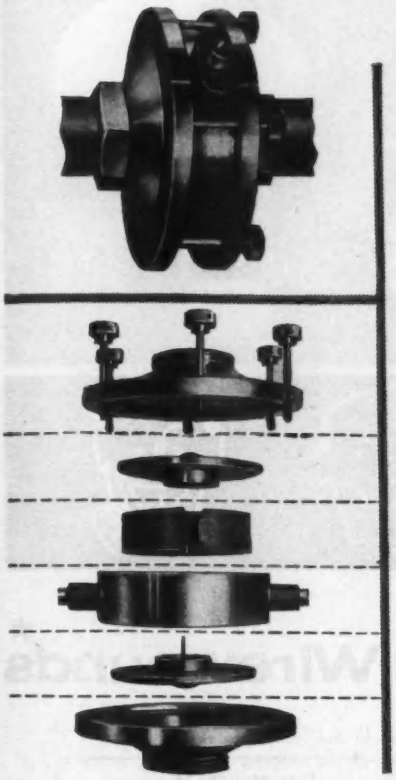
MEASUREMENT METERS

suit every purpose



The new UNIPULSE all-purpose liquid meter designed by MEASUREMENT LIMITED is an important advance in accurate industrial metering of fluids in chemical compound manufacture, process engineering involving fluids, and food and drink production.

The UNIPULSE meter successfully operates with liquids varying in viscosity, acidity, alkaline content and temperature, and can be linked to a wide range of indicating or dispensing control devices.

The clean design eliminates the conventional gear mechanism, enabling fluids to be dispensed to an unprecedented accuracy.

Write to the Sales Manager, MEASUREMENT LIMITED for full particulars.

meters are matters for **MEASUREMENT**

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Tel: Delph 424 (5 lines) Telegrams: SUPERMETER, Dobcross

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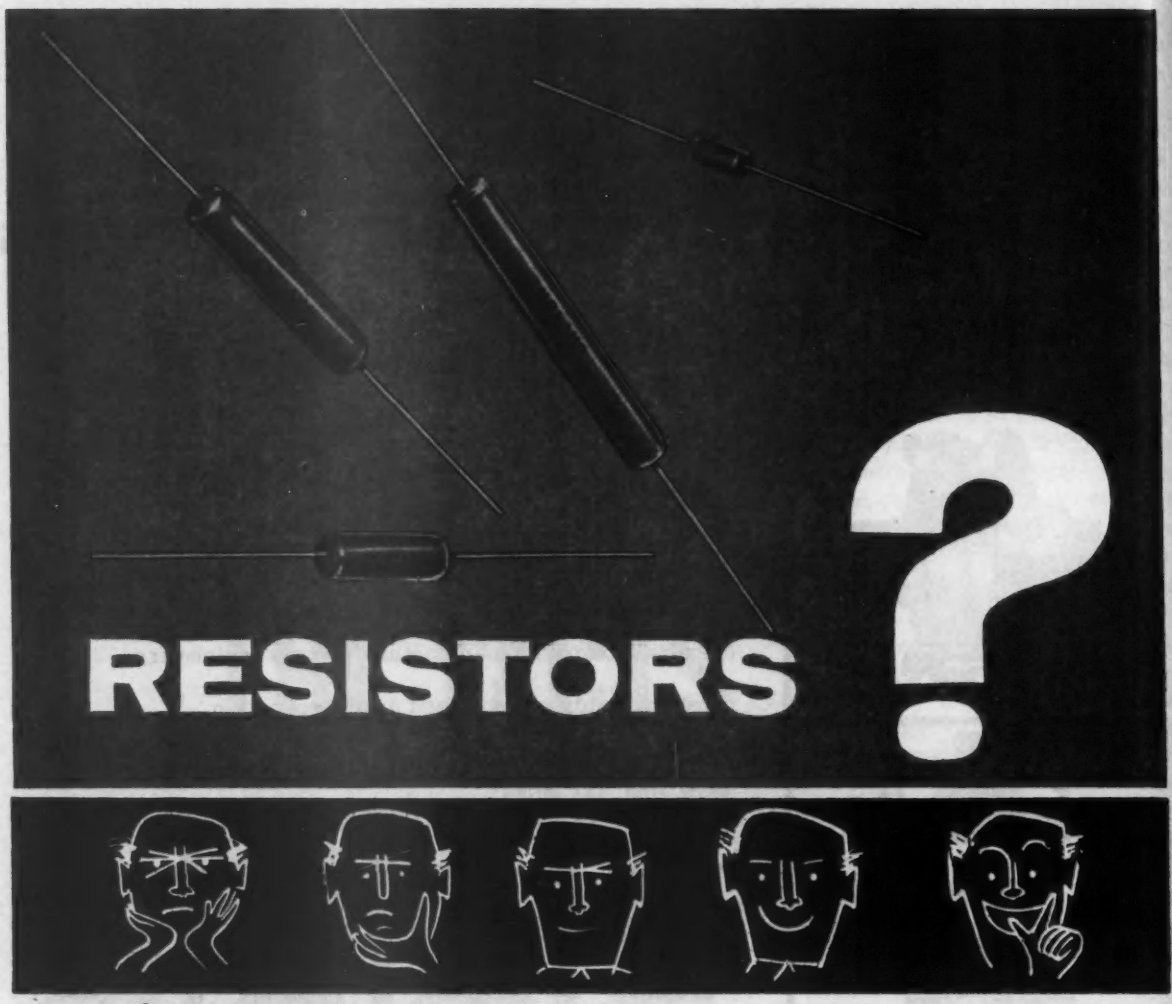

Don't hesitate – always specify PAINTON Wirewounds ★

Examples of our miniature range

Rating (at 20°C) Watts	TYPE	Resistance Range ohms		Tolerance
		Min	Max	
4	MV1A	1 10	9·9 6,800	10% 5%
7	301A	2	68,000	5%
10	302A	4	140,000	5%
5	306A	1	33,000	5%

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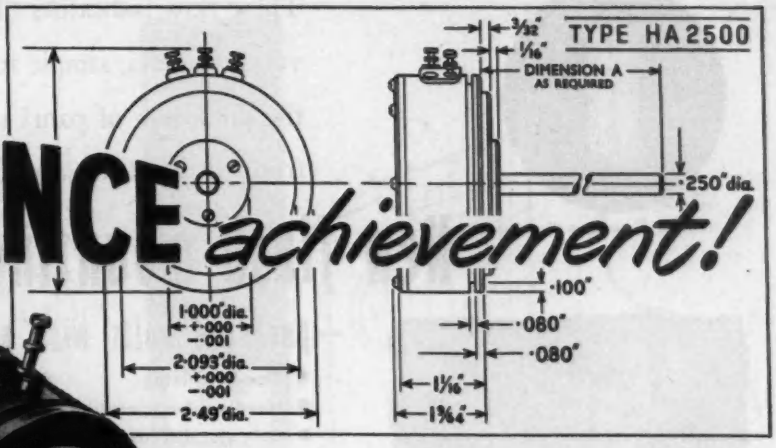

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TYPE HA2500

HIGH LAW ACCURACY
without cam correction

In this new continuous rotation type HA 2500 Potentiometer intensive research has made possible high accuracy with much improved mechanical stability. A precision machined light alloy body, an accurately ground ball-bearing mounted spindle – a patented design that eliminates cam correction, combine to give the following advantages :—

- LOWER TORQUE
- LONGER LIFE
- REDUCED WEAR
- LOWER COST

BRIEF SPECIFICATION

Resistance range	100 to 100,000 ohms.
Law Accuracy (Absolute)	± 0.25% or ± 0.10%
(Independent law accuracy to closer limits)	
Maximum Starting Torque	1 oz/in.
Maximum Ganged Sections	Four.
Maximum Tappings	Nine.

Full technical details and dimensional drawings in Data Sheet No. 100 available on request.

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If our standard types do not meet your particular requirements, our research and development engineers are at your service.

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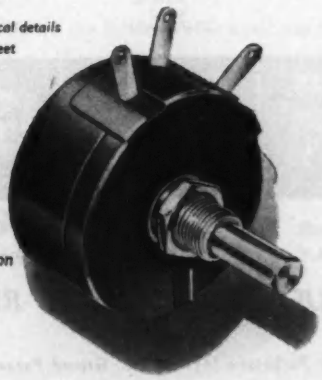
SUTHERLAND ROAD · HIGHAM HILL · WALTHAMSTOW · LONDON · E.17.
Telephone No. (and for Cables) LARkswood 1118/9

. . . *and* ANOTHER ADDITION TO THE COMPREHENSIVE RELIANCE RANGE

The **TYPE W3** (3 WATT)

This model conforms with specification DEF-5121 style RVW 7 & 8 (formerly RAC.RAD) and is a fully sealed unit with integrally constructed moulded cover. Also available in unsealed version.

Full technical details in Data Sheet No. 9



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GD.60

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Front view. Common to all models.

These flow indicators (Type 715 series) are versatile units, simple to install and occupying the minimum of panel space, with no awkward front of panel projections.

New flush mounting purge meters

—packaged units with pressure regulators

Type 715D. Back view.

- **One-hole fixing**
- **No projections on front of panel**
- **Needle valve operation by coin slot**
- **Coin slot discourages unauthorised adjustment**
- **Self contained units reduce installation costs**
- **Can be spaced as close as 4" centres**

The series consists of four instruments

Type 715A—Simple indicator
715B—Indicator with needle valve
715C—Indicator, needle valve, and constant pressure regulator
715D—Indicator, needle valve, and differential pressure regulator

ROTAMETER
FLUID MEASUREMENT AND CONTROL
FLOW-DENSITY-LEVEL

Leaflet CC.2021/34 is free on request

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GD320/G34

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Shaded Pole Constant Speed 1/300–1/140 HP	Series Wound Variable Speed 1/100–1/10 HP	Series Wound Variable Speed 1/40–1/5 HP	Capacitor Constant Speed 1/150–1/30 HP	Capacitor Constant Speed 1/40–1/5 HP	Split Phase Constant Speed 1/40–1/5 HP

Shaded Pole Constant Speed 19–330 RPM	Series Wound Variable Speed 25–800 RPM	Series Wound Variable Speed 22–800 RPM	Capacitor Constant Speed 17–680 RPM	Capacitor Constant Speed 20–700 RPM	Split Phase Constant Speed 20–700 RPM

Shaded Pole Constant Speed 1/4–18 RPM	Series Wound Variable Speed 0·5–60 RPM	Series Wound Variable Speed 0·3–60 RPM	Capacitor Constant Speed 0·3–19·5 RPM	Capacitor Constant Speed 0·2–19 RPM	Split Phase Constant Speed 0·2–19 RPM

REGD. TRADE MARK
PARVALUX
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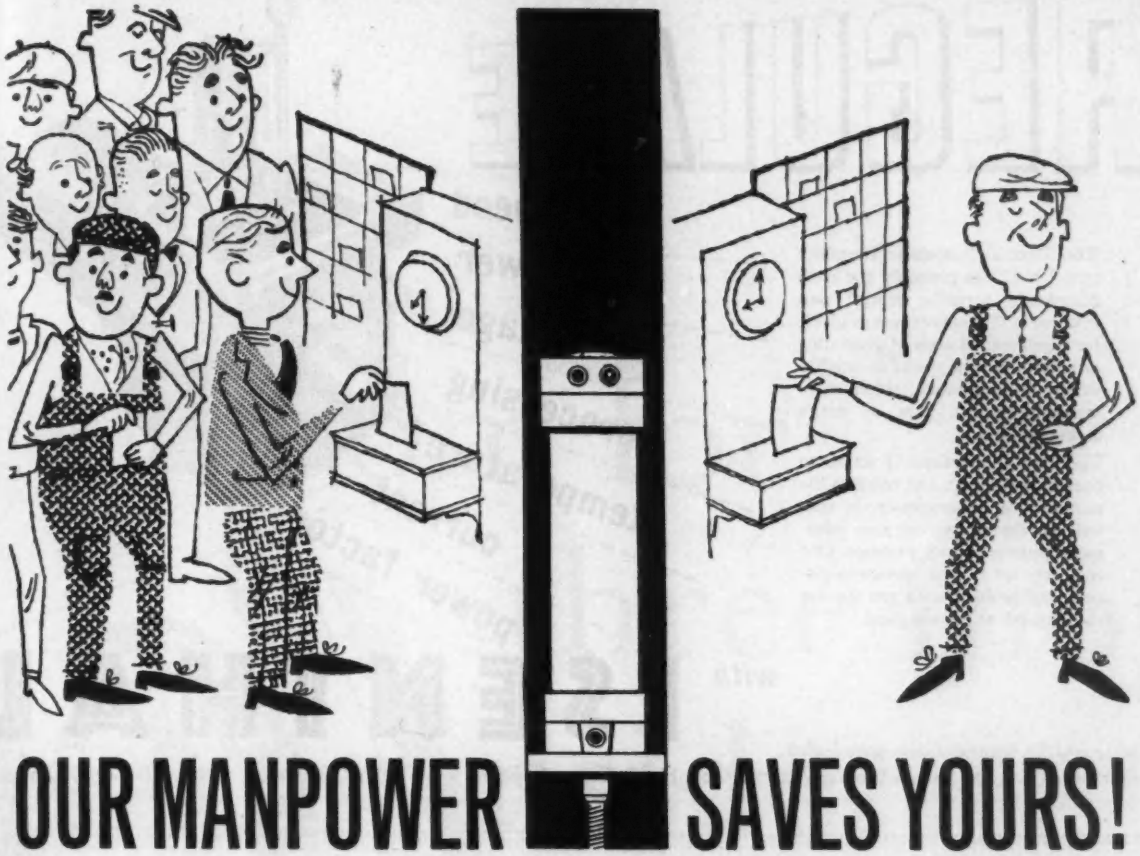

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BALDWIN TECHNICAL REPRESENTATIVES cover the British Isles. They are experienced fluid power engineers, who will quickly show you how to harness waste or under-used power by fitting Baldwin equipment which, because of its unit construction, can be supplied from stock quickly.

Write now for the Fluid Power Catalogue C/503

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Fluid Power Division

Baldwin Industrial Controls

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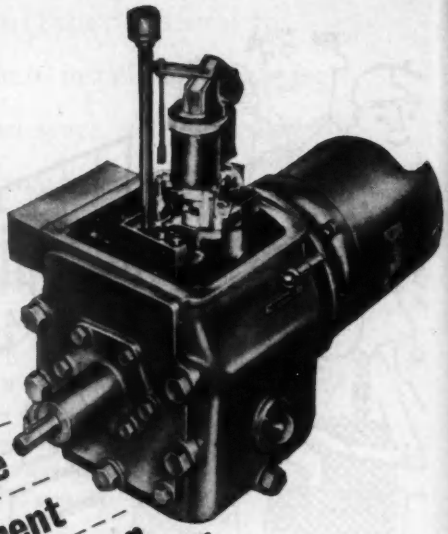

The Isenthal Automatic Regulator type "N.C." is probably the most completely versatile control unit obtainable. There are types available for regulating all sizes of generating or processing equipment to satisfy a variety of conditions, either automatically, or as part of user's control system.

The "N.C." Regulator is simple to operate and adjust, and requires the minimum of maintenance. It may well be the answer to your automatic process control problem. Our engineers are at your service to discuss your problem with you and are ready to call at your request.

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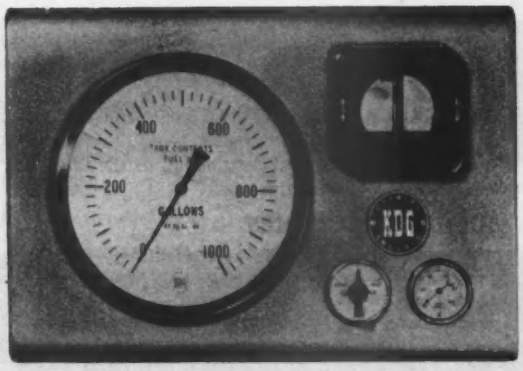
Please send for illustrated descriptive leaflets.

Isenthal & Co. Ltd., Ducon Works, Victoria Road, North Acton, London, W.3. Tel. ACOrn 3904. Grams: Isenthal, London.



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Instrument and all accessories housed together as one unit, giving complete and accurate picture of storage, air flow and pressure conditions at a glance.
Supplied completely piped, connected up and tested ready for immediate use.
Self compensating air regulator fitted.
Multiples of similar tanks can be gauged from one unit.
Additional indicators available for alternative reading positions.

Hand pump types can be substituted where compressed air is not available

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CRAWLEY KDG LONDON

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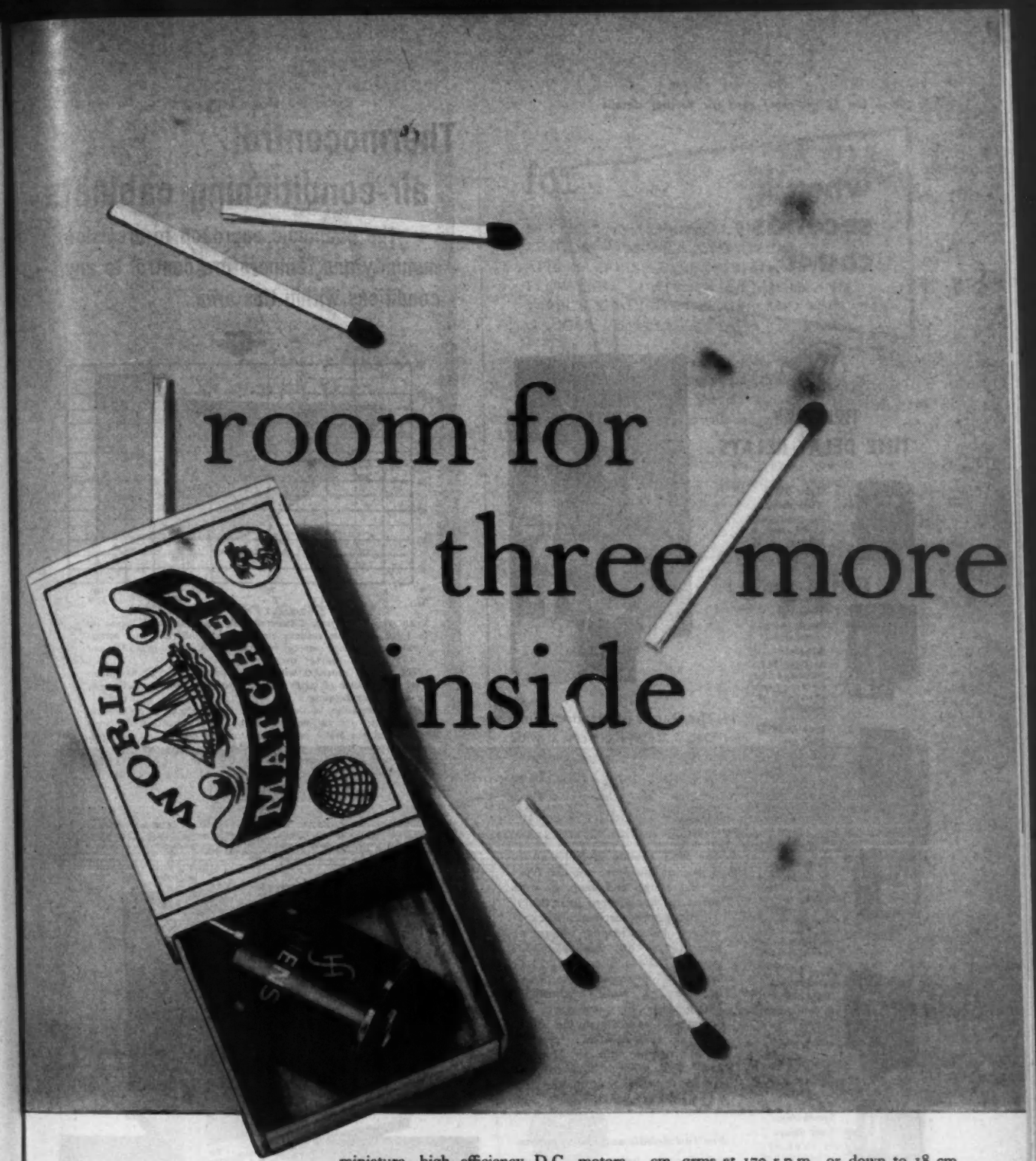

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when seconds count . . .

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Time delay:
Any fixed period in the range of approx. 2-10 seconds.

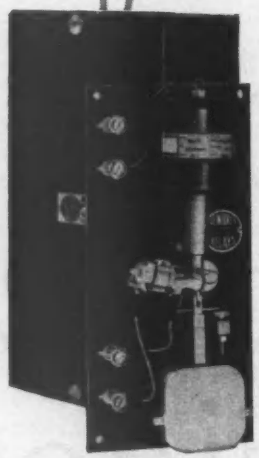
Type MSTD Inverted
Time lag:
Mechanical escapement.
Ranges:
As Type MSTD but delay period commences when coil is de-energised.

Type DCMTD
Time lag:
Mechanical escapement.
Ranges:
3-5 seconds
5-15 seconds
15-20 seconds

A.C. Adjustable Timer
Time delay:
By Synchronous Motor. Min. setting 10% of maximum. Shortest Period 10 seconds. Max. setting up to several hours.

Type SS Synchronous
Time delay:
By Synchronous Motor, from a few seconds to many minutes.

Type DSS Synchronous
Time delay:
As Type SS. Synchronous but with two time delayed circuits.



The Range of Hendrey Time Delay Relays covers a wide field, and types are available permitting time delays from a few seconds to several hours.

The MSTD Relay illustrated above is one of the most popular types in the range and finds a wide variety of applications in industry. Time lag is by mechanical escapement. The following ranges of time delays are available: 3-5 seconds, 5-15 seconds, 15-30 seconds, 30-60 seconds, The period of delay is readily adjustable within the limits specified and commences immediately the coil is energised. The switches however do not operate until the selected delay has expired, and can be arranged either to "make" or "break" as desired.

For full details and specification ask for the appropriate Catalogue Sheet.

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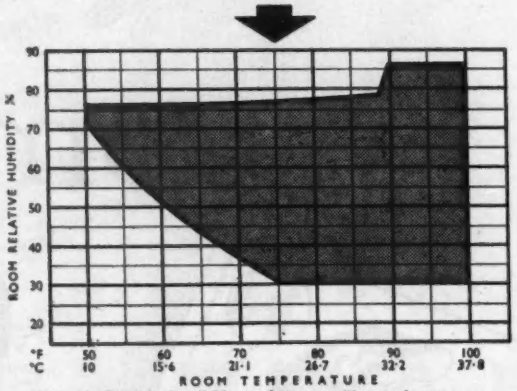
. . . the economic approach to precision humidity and temperature control to any conditions within this area

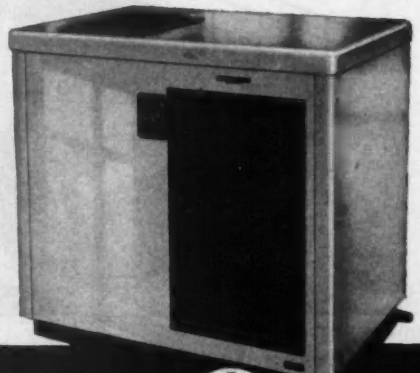


With Air Conditioning Cabinets of the type illustrated, rooms up to 3,000 cubic feet capacity can be conditioned and with agreed installation layouts can be maintained to within ±0·5°F and ±0·75% R.H. settings overall.

The unit is provided with an air outlet raised above bench level and a range of larger units is also available to special design for unusual applications.

The specification of the standard unit includes a replaceable glass-ail filter for air entering the cabinet; centrifugal fan with belt driven fan motor and starter; cooling coil of up to 35,000 B.T.Us extraction per hour for reduction of either temperature or humidity; air heater with built-in high limit thermostat; room thermostat with relays to operate electric heater when the temperature is low, or cooling coil when the temperature is high; humidistat to control relative humidity through evaporative humidifier.

Our specialist Engineers will be pleased to examine and recommend conditioning equipment for YOUR schemes to ensure maintaining stringent conditions at economic cost.



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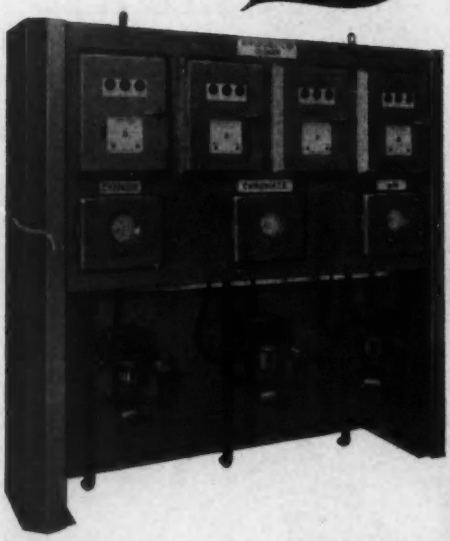
NUCLEAR CHEMICAL ELECTRONIC

Effluent and Trade Waste INSTRUMENTATION BY Lock



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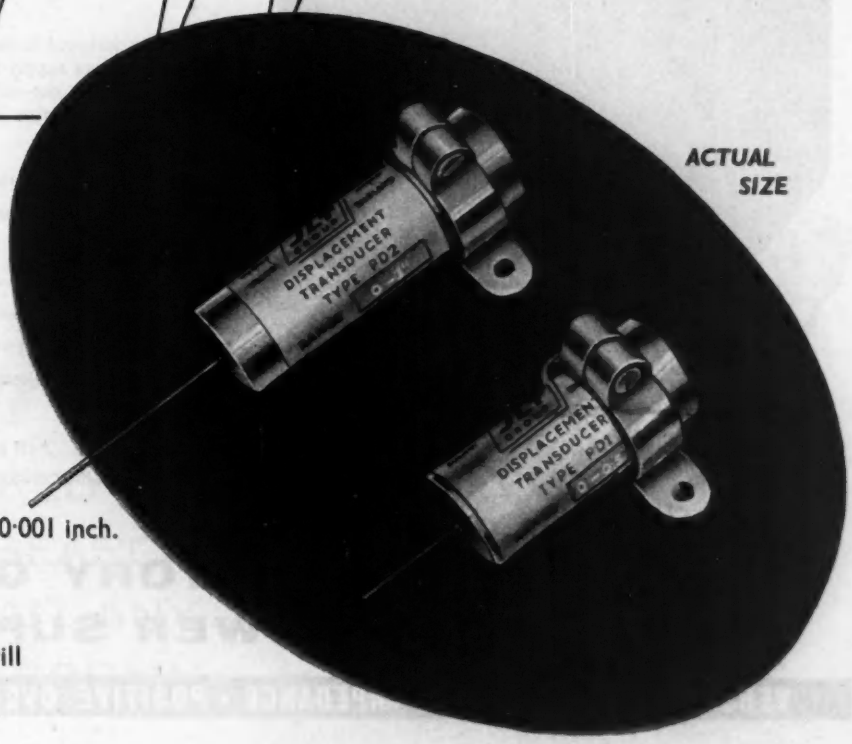

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- Extremely sensitive—measures axial displacements down to 0·001 inch.
- Can be orientated through 360° axially.
- Less than 1 gm force will displace shaft.
- Easy to install.

BRIEF SPECIFICATION

	PD1	PD2	PD3
Displacement Range:	0–0·5"	0–1"	0–2"
Potentiometer Resistance:	4,500 ohm	9,000 ohm	18,000 ohm
Maximum Operating Voltage:	20V	40V	80V
Maximum Slider Current:	5 mA for all models		
Resolution:	0·2%	0·1%	0·05%

These Transducers will measure static or slowly varying displacements with an accuracy of 0·5% of full range output over a temperature range of −40°C to +100°C. The miniature precision potentiometer element is wound with a platinum alloy wire giving an absolute discrimination of 0·001 inch.

They are particularly suitable for profile following, position indication and the measurement of material deformation.

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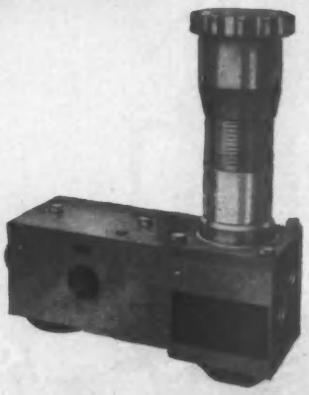

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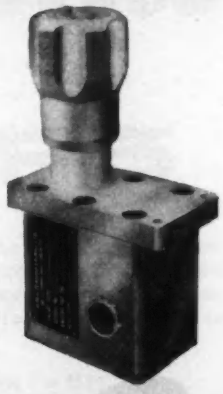

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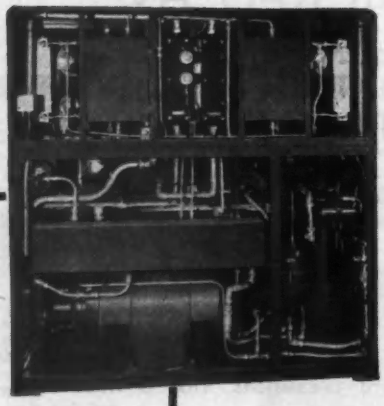

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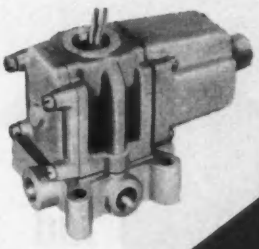
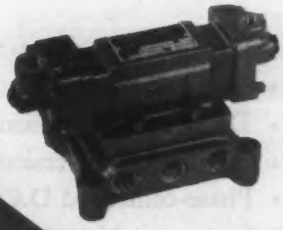
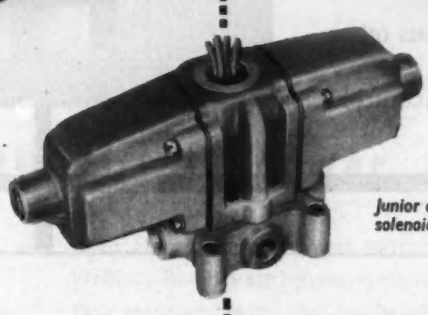


Junior and SGA Series single solenoid operated spring return valves



Double pilot operated spring centred valves



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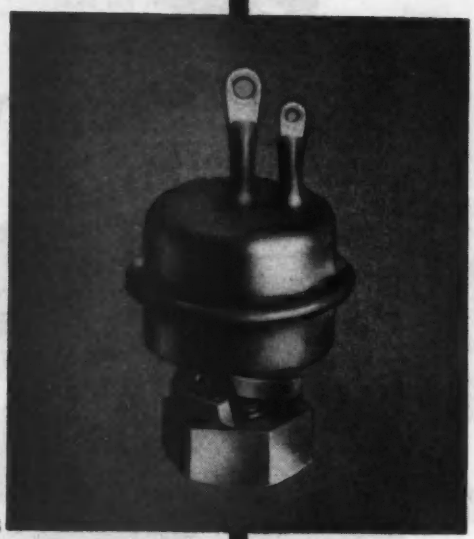

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CX10/50	50	10	0·1	CX5/50	50	5	0·1
CX10/75	75	10	0·1	CX5/75	75	5	0·1
CX10/100	100	10	0·1	CX5/100	100	5	0·1
CX10/150	150	10	0·1	CX5/150	150	5	0·1
CX10/200	200	10	0·1	CX5/200	200	5	0·1
CX10/250	250	10	0·1	CX5/250	250	5	0·1
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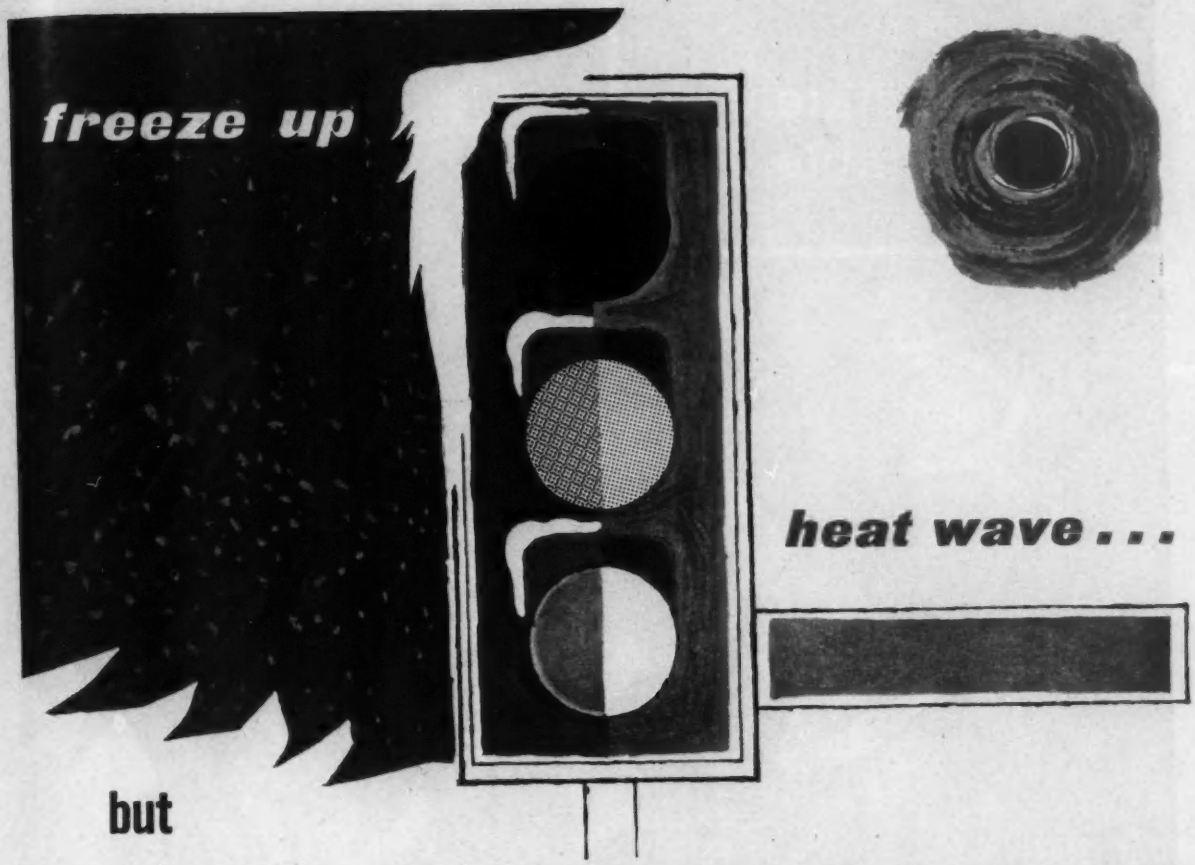

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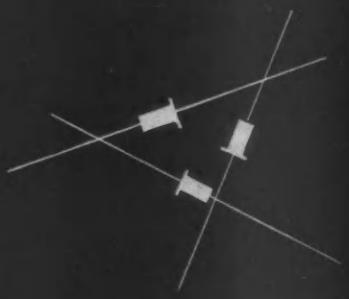

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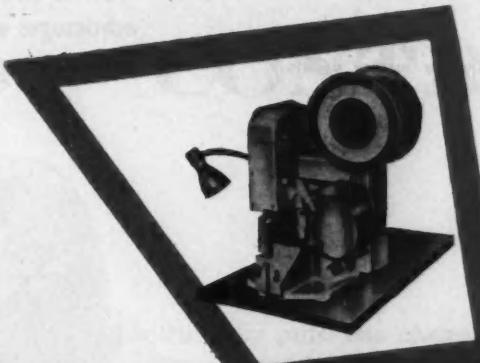
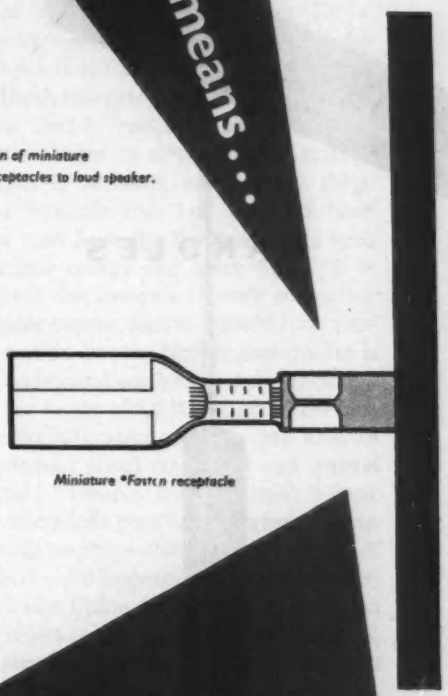


the means...

Application of miniature Faston receptacles to loud speaker.



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Philco Model 1020 17" Television Receiver.

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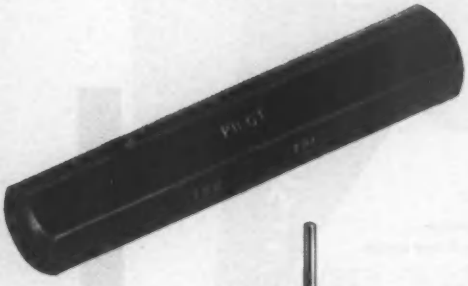

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AUGUST 1960 VOL. 3 NO. 26 CONTROL

Return from Moscow

A FAVOURITE story among delegates at the Ifac Congress was the one about an American quiz for which the first prize was a week's stay in Moscow: the second prize was *two* weeks in Moscow. Certainly delays and confusions were suffered by some people at this great international gathering, but most have tended to forget the petty irritations, the red tape that seemed more tangled for being strange and foreign. Much more important impressions have been retained. There is a full, interpretive, and in places brilliant, review of the congress on p. 84 ff of this issue, and we would advise all readers to study at least a part of it.

It is plain that the congress has been only partly successful, the threefold objective having been about one-third achieved. Theory, components, and industrial applications were each to have received the full treatment, but only theory did. There was a great clarification of the theoretical position, and once again it was made obvious that technology, like peace, is indivisible. The U.S.A. and the U.S.S.R. are inevitably making the biggest contributions, but the relatively small British offering has been unexcelled in quality.

Some delegates have been asking why the Soviet Union is devoting so much effort to advanced theory, for clearly the immediate return would be greater if technical manpower were devoted to problems of the moment rather than of the longer term. One explanation of the endeavour to push theory so hard is the Russians' sheer love of mathematics. Another possibility is that, lacking western facilities for experimental development, Soviet technologists are forced to do the maximum amount of work on paper before venturing on to realization. Yet a third elucidation may be sought in terms of politico-economic philosophy.

It may be—and some delegates are firmly of this opinion—that the magnitude of Russian theoretical effort is a real measure of Russian practical application, but if this is true it has not been shown to Ifac congressmen. The technical visits that were arranged for delegates—at least in the Moscow area—were often disappointing. One was, of course, impressed by the unmanned production-line at the famous Moscow bearing factory, where (to consider one detail only) a machine automatically inspects as many as twenty dimensions and rejects faulty parts. One admired also the production of a watch in every two man-hours at the highly mechanized watch factory, although this is far from being an 'automated' plant. The Moscow Institute of Automatics and Telemechanics demonstrated, among other things, some pretty devices for pneumatic computing, and it has what is said to be an optimizing controller for a twelve-parameter system. But the showing at the Moscow Computation Centre was poor. There a disgruntled British delegate remarked of one Russian computer that it was little better than an electromagnetic abacus (a comment that seemed more significant in Moscow, where every shop-assistant and waitress does her sums on bead frames). How then have the Russians made such strides in nuclear energy and space flight? It is just possible that vast amounts of crude computing machinery under superb direction could have produced these results, but the likelier explanation is that the most advanced equipment is not shown.

Let us be fair to the U.S.S.R., which as the host country is especially vulnerable to this kind of criticism. Canniness about equipment was general at the congress. Therein lay its partial failure. Military considerations obviously weighed heavily, and commercial secrecy—that supreme waster of technical talent—also appears to have a counterpart in the Soviet Union. Consequently, little was revealed by *anyone* with regard to hardware.

Actually, the best balance between theory and practice was struck in the British contribution, small as it was in absolute size. However, other countries interpreted the scope of the congress more broadly than did the U.K., and we may suppose that a greater number of British papers would have been submitted if this had been foreseen.

The first Ifac Congress was without doubt a most important affair for control engineers everywhere, and the return on the investment of effort in it has been substantial. An observation to this effect was made by a delegate in pontifical mood during a lull in the proceedings; 'The Congress', he said, 'Is An Historical Event'. 'Yes', added a colleague, 'it was historical *before it started*—the papers were all a year old!' The quip deserved the laugh that it raised: but on reflexion we suggest that it may more aptly be taken to commend than condemn.

LETTERS to the EDITOR

Grievous confusion

SIR: It is a matter of the highest importance that the fundamentals of our thinking should be correct, even if this requires considerable revision of existing textbooks. We must distinguish between the academic kind of rigour which is based upon a purely *a priori* conception of mathematics, and a second kind of rigour which seeks by great care in specification to avoid contradictions and ambiguities. The first kind has largely been exploded in the last fifty years, while the second does not disdain the help of experience, but requires the utmost simplicity and depth of understanding.

The Editorial on p. 79 of your July issue and F/Lt. Flegg's article on p. 105 thereof raise fundamental issues about which there is at present grievous confusion, namely

(i) When a function $h(t)$ is related to a 'transform' $f(s)$ is s an ordinary number or, as conceived by Heaviside, an operator?

(ii) Should the extra factor s advocated by F/Lt. Flegg be included or not?

(iii) There is a connection between differentiating $h(t)$ and multiplying $f(s)$ by s; also between integrating $h(t)$ and dividing $f(s)$ by s. What is the proper formulation of these connections?

For (i) above, we consider the operational approach to be superior but this is largely a psychological preference rather than an essential issue upon which a wrong decision may lead to error, and we therefore do not propose to discuss it further here (though possibly elsewhere).

For (ii) above, we can only welcome F/Lt. Flegg's advocacy of the extra s and the dimensional consistency thus gained. It is the third item that is our main concern, because inadequate formulation here can lead to serious errors.

Consider the integral

$$\phi(a, t) = \int_a^t h(\lambda)d\lambda \qquad (1)$$

in which information is conveyed not only by specifying the integrand $h(\lambda)$ but also by specifying the lower limit a. This integral is preferably written

$$\phi(a, t) = \int_{-\infty}^{t} h(\lambda)\, H(\lambda - a)d\lambda \qquad (2)$$

where $H(x)$ is Heaviside's unit step, zero for negative x and unity for positive x, because the part played by a is now explicity written into the integrand. The limits now 'indicate merely that all the integrand prior to time t is to be included. The lower limit can here be replaced by $a - \epsilon$ where ϵ is positive and as small as we please (but not zero) because the integrand itself tells us that there is nothing to integrate for lower values of λ than a, but in the general case the lower limit $-\infty$ should be retained so that 'integration' means 'integration of all the integrand up to a (variable) point', here t. The symbol $-\infty$ does not necessarily indicate an enormous negative number but simply a number low enough for all the integrand to be included. The form of Equation (2) makes clear that the integrand of Equation (1) is not really $h(\lambda)$ but $h(\lambda)H(\lambda - a)$.

If integration is always used in the above sense of integration from $-\infty$ to t or integration of all the integrand up to t, then differentiation of $h(t)$ n times will multiply the transform $f(s)$ by s^n, and integration (from $-\infty$ to t) of $h(t)$ will divide $f(s)$ by s without any additional terms whatever. The formulae given in Laplace-transform textbooks can be derived as special cases of this provided that a is taken as zero in Equation (2) above, and the operand or original is treated correctly as $h(\lambda)H(\lambda)$ and not simply as $h(\lambda)$. Even so, however, the lower limit of integration $-\infty$ can be replaced by any negative number, however large or small. It cannot, however, be replaced by 0, which is an 'over-determination', still less by $0+$, which is an error.

An analogous situation occurs in the specification of a cartridge for use with a rifle of 0·303 in. diameter bore. We can specify a cartridge of diameter 0·303 in. or we can specify a cartridge to suit the rifle, but we cannot specify the diameter 0·303 in. and simultaneously demand that the cartridge will fit the rifle. Requiring the cartridge to fit the rifle corresponds to replacing the lower limit $-\infty$ by $0-$ for the integration of $h(\lambda)H(\lambda)$. If, however, this limit is replaced by $0+$ as advocated by F/Lt. Flegg, the corresponding situation is that in which the cartridge is too large for the bore provided and therefore useless.

Research Dept., J. W. HEAD, C. G. MAYO
B.B.C.

Monkeys and men

SIR: Mr. Rudkin says* that a 'cybernetic company' "can only be a company whose business is to engage in that science". Why? A 'model factory' *might* be a factory making models, but most people would take the phrase to refer to a factory run on model lines.

It may be right to say that the distinction between (what he calls) an 'automatized factory' and (what I call) a 'cybernetic factory' is one of degree. So is the distinction between the brain of a monkey and the brain of a man. Mr. Rudkin may call distinctions based on degree 'artificial' if he likes; but they have important consequences.

The United Steel Co's Ltd STAFFORD BEER

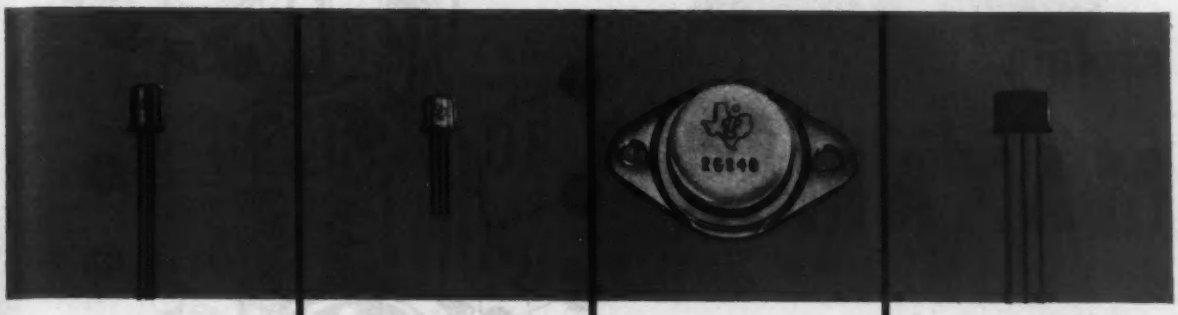
* '*Letters*' *last month, p. 81*—EDITOR.

PUBLISHER'S COLUMN

Welcome news

We are quite out of sympathy with the insularity of some of our countrymen toward the U.S.A. and the 'American way of life'. Personally, we might perhaps find it harder to enjoy life, liberty, and the pursuit of happiness exactly as they do on the other side of the Atlantic: but we do not react instinctively against every tint and wrinkle that distinguishes Uncle Sam from John Bull. On the contrary, we welcome American ideas in many ways, and see no reason why their entry should be resented. Some of our friends are less tolerant in this regard, but they still pay full respect to American industrial know-how, and admit that we have plenty to learn from it. The grudging admirers, as well as the more enthusiastic pro-Americans like ourselves, will be glad to see the new feature that is beginning in CONTROL *this month. This regular report on American control engineering progress is the work of a strong team at M.I.T., and we are delighted to welcome these well-known contributors to our magazine. Their newsletter is going to be widely read, and we think it will do a lot of good all round.*

COMPUTER TRANSISTORS FROM TEXAS



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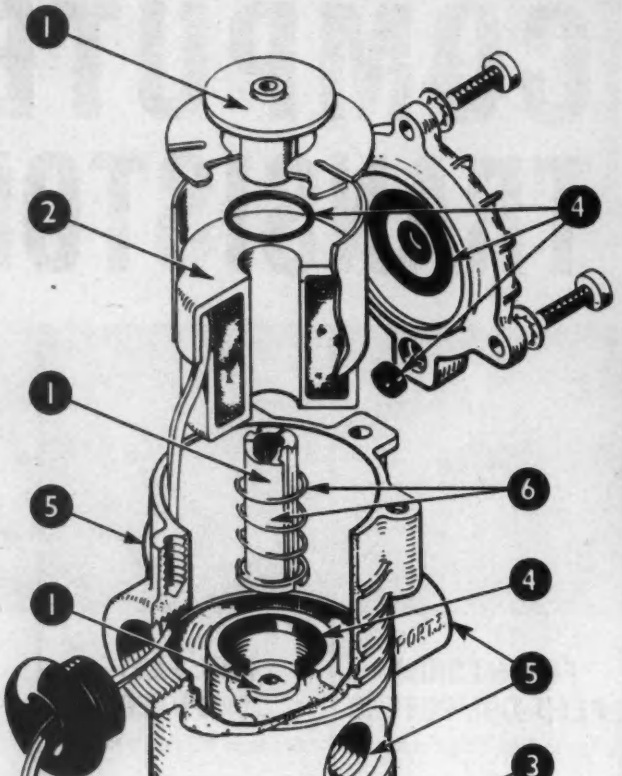

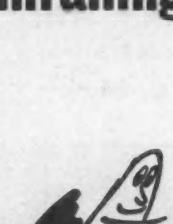

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VIEWPOINT

Howard H. Rosenbrock, Research Manager of Constructors John Brown, feels that automatic control can only advance by scientific thinking, for he sees the . . .

DECLINE OF EMPIRICISM

It is a commonplace of the history of automatic control that in the process industries practice came long before theory. Controllers were invented and developed to meet an empirical need, and the reasoning which underlay their operation was never mathematical. They owed nothing to the science—then in its infancy—of automatic control. They were applied by engineers who, from long experience, had developed an intuitive understanding of the problems to be overcome.

Moreover this approach, unscientific, intuitive and empirical, was entirely successful. When theory began to be applied, in the middle nineteen-forties, it served chiefly to explain why things were done as they were: why some plants were simple to control and others difficult. It did not lead, and still has not led, to any significant or widespread improvement in methods of control or in control equipment. Much early enthusiasm has foundered on this rock.

There are, I think, two reasons for this situation, which differs significantly from the situation in other fields of control. The first is that the process-control engineer was called on to solve only problems which were simple and unexacting compared with those in other fields. Local, independent control-loops were used, and a fast response was not usually needed. For this reason the problems could be solved without the aid of theory. Secondly, when theory became available, it turned out that most chemical processes were excessively difficult to analyse. This meant that the advantages of better control were more difficult to realize than in other fields.

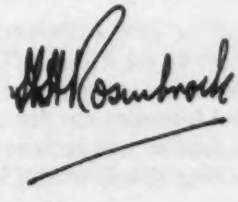
Yet it seems that the old empirical approach has now lost its momentum for further advance. Three-term controllers are no more effective now than their predecessors of fifteen years ago. Miniature instruments, electronics, and all the improvements of detail, important as they are, have left control about as effective as it was before. Meanwhile, the cost of instruments and controllers on new plants has grown to such a proportion of the total cost that further proliferation of control loops is unlikely to bring much economic gain.

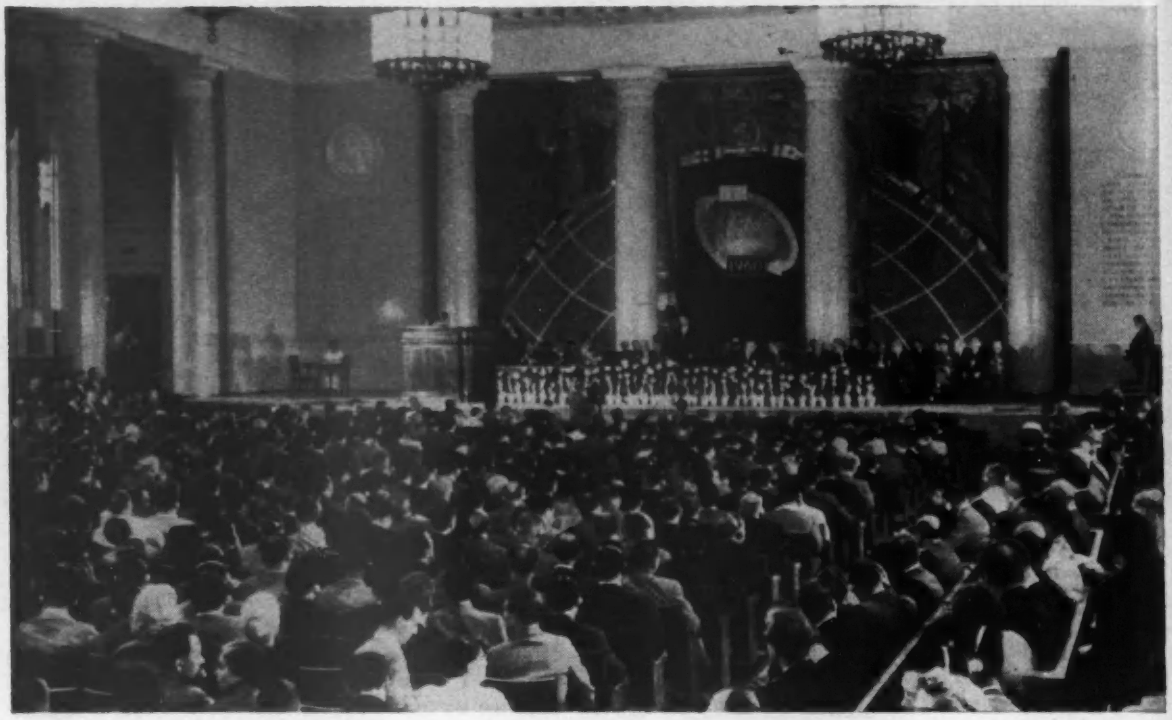
It seems to me that future progress will come in two directions: quality control and centralization. The first of these depends on our ability to develop suitable instruments, and then on our being able to close a control loop around a large section of plant. There will be more difficult control problems here than have been common in the past. Centralization of control is often equated with 'computer control', although I believe that after the first experimental stage the controller may very likely be analogue, or at least hybrid. A central controller may well be cheaper than a multitude of separate controllers, and it offers scope for more sophisticated and more effective control provided that we have enough data to design it correctly.

In both these directions I believe that the empirical approach will be inadequate: we shall be forced, if we are to succeed, to adopt a consciously scientific approach. Experiments on a large scale will be needed to obtain the data, and control systems will have to be designed on the basis of these data for the particular job they have to do. Most of the experiments, and much of the design work, will necessarily be done by chemical manufacturers.

This brings me to my main point. In the development of our present controllers, the instrument manufacturers acted as a clearing-house for the accumulating experience on which the instruments were based. They applied their instruments on different plants in different conditions, and everyone benefited from the combined experience.

In the phase that we are entering, how will this interchange of knowledge be maintained? We shall all be the poorer if the same problem has to be solved independently each time it occurs, and if equipment is not subjected to the test of different environments. I suggest that conscious efforts, whether formal or informal, will be needed to avoid these dangers.





The meaning of Ifac

Moscow was privileged to set the scene for the first international congress of Ifac. Mounted on a magnificent scale, the congress brought together 1111 delegates from 29 countries. This tremendous occasion, which embraced theory, components, and industrial applications, is reviewed for CONTROL *readers by five well-known authors: J. G. Truxal, J. H. Westcott, R. J. A. Paul, R. J. Redding and D. B. Foster.*

BACKGROUND

IN THE AUTUMN OF 1956 A CONFERENCE ON AUTOMATIC control was held by the *V.D.I.-V.D.E. Fachgruppe für Regelungstechnik* in Germany, and it was there that an international federation was first proposed. The proposal was not received with acclamation. One objection was that there were already enough international bodies to call conferences together. The representatives were finally persuaded by the possibility that a new federation might encourage collaboration between east and west, and a first constitutive assembly consequently gathered in Paris in September 1957. There, after some discussion of details, the International Federation of Automatic Control (' Ifac ') was formally brought into existence, and its first congress was planned to meet in Moscow in 1960. The arrangements then went steadily, and the congress met on June 27 to July 7.

By its constitution Ifac is composed of national organizations. There are 29 of these at the present time.†

† Argentina, Australia, Austria, Belgium, Bulgaria, Canada, China, Czechoslovakia, Denmark, Finland, France, German Democratic Republic, German Federal Republic, Hungary, India, Israel, Italy, Japan, Netherlands, Norway, Poland, Roumania, Sweden, Switzerland, Turkey, U.K., U.S.A., U.S.S.R., and Yugoslavia.

The United Kingdom is represented by the British Conference on Automation and Computation (B.C.A.C.), which is a combination of established institutions gathered into three groups: Group A for engineering applications, Group B for computation and automatic control, and Group C for sociological and economic aspects. Further details may be obtained on each of these three Groups from their Honorary Secretaries[1].

There were about eighty members in the British delegation to the Moscow Congress, led by Mr John F. Coales (Cambridge University) with Professor G. D. S. MacLellan (Glasgow University) as his deputy. The British papers are to be discussed at a symposium in London on September 27–28, where there will also be a brief report on other contributions. A list of papers, and a registration form for attendance at the symposium, may be obtained from The Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.

John G. Truxal gives an American

EAGLE'S-EYE VIEW OF THE CONGRESS

and then comes down for a closer examination of some theory papers

A DOMINANT IMPRESSION OF THE DELEGATES FROM OUTSIDE the U.S.S.R. certainly concerned the whole-hearted support given to the Russian Organizing Committee by the Russian Government, the Academy of Sciences, and the Institute of Automatics and Telemechanics. The congress itself was startingly well organized, with all aspects from local transportation to technical translation running smoothly and contributing markedly to the success of the meetings (the Government even issued a special stamp commemorating the congress). The delegates were most impressively entertained. The particular highlights were the anticipated excellence of the Bolshoi ballet, the somewhat surprising elaborateness of the banquet, and finally the totally unexpected and breath-taking impressiveness of the formal reception tendered on behalf of the Academy of Sciences in the Kremlin Palace.

The support, both financial and resource-wise, given to the Organizing Committee in many ways could never be obtained in the U.S.A., where it is difficult to visualize any such meeting being opened by officials of Cabinet rank, or sponsoring societies being able to obtain the services of some forty technically trained translators for the full week. The support exemplified by such specific arrangements seems to be the result of a remarkably strong emphasis of the Russian Government on automation and automatic control — an emphasis which undoubtedly is partially rooted in military applications, but which seems to be strongly based upon a conviction of the potentialities of automation for not only increasing productivity, but also improving the life of the working man.

The above idea is perhaps approximately summarized in the opening remarks by V. A. Trapeznikov, President of the Institute of Automatics and Telemechanics—remarks which were echoed frequently throughout the week both at technical sessions and during individual conversations with Russian engineers: 'Not only will automation raise productivity, but it will also radically change the very nature of labour . . . Automation will help turn manual labour more and more into mental work . . . so that man's energy and vital strength directly involved in production may be utilized to an ever greater degree not for process control or—less so—for manual labour, but to produce and realize novel engineering ideas, such as would further relieve man of direct participation in production and would give him abundant life and more leisure. The higher labour productivity and expanded material production stimulated by automation will sharply improve the standards of living and reduce the working day to but a few hours in the near future'.

The publicity given to the congress in the Russian press, the support apparent throughout from the Government, and the intense interest in the U.S.S.R. (and the other communist countries, such as China) in automatic control (as another example, we were told that 7·5% of the U.S.S.R.'s Academicians were directly working in the automatic control field—not including related fields such as computer technology), seem to reflect the emphasis of the Government on automatic control as an essential tool not only for guidance of space vehicles, but also for the rapidly increasing automation of industry.

The emphasis on automatic control in the U.S.S.R. can perhaps be illustrated quantitatively by a consideration of the display of Russian books, which was indeed impressive, constituting approximately half of the total display (the United States was rather inadequately represented). More impressive than the large number of different Russian titles (which we estimated at well over 1000), however, were: (1) The very large percentage of the books devoted to specific aspects of industrial automation (e.g., automation in the steel industry or in specific chemical industries), with first printings of such books usually 4000–6000 copies. (2) The enviable translation program, under which the majority of the important American works have appeared in Russian, and usually without an excessive time-lag. Included are works on both general theory and specific areas (e.g., magnetic amplifiers). The extent of the translation program is certainly in part the result of the respect of the Russian engineers for American efforts,

[1] These may be reached at the following addresses: Group A, c/o Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1; Group B, c/o Institution of Electrical Engineers, Savoy Place, London, W.C.2; Group C, c/o British Institution of Management, 80 Fetter Lane, London, E.C.4.

We regret an error in last month's report of the congress. On p. 86 a general criterion that had been discussed by Fuller was given incorrectly. The condition should have been stated as 'where $v \geq 0$', not 'where $v = 0$'.—EDITOR.

is also partly associated with the vastly greater amount of reading done by the Russian research engineers (who frequently asked questions about American articles which few of the Americans had read), and finally, is partially the result of strong Governmental support of the translation program. (3) The large printings of theoretical books. For example, the first printing was 10,150 for V. S. Pugatchev's 'Random Function Theory and its Application to Automatic Control' (1960), and 15,000 for Feldbaum's 1959 book, 'Computing Devices in Automatic Systems', both quite advanced treatments. There seem to be the usual large number of parallel and essentially similar introductory books, but in each case first printings typically were 20,000–30,000. These figures, impressive when compared with typical American total-sales figures (which are usually appreciably less than half as much for comparable works), reflect the remarkably extensive research and development activity in automatic control in the U.S.S.R. (a level which was even more impressive to those delegates who had travelled throughout the Soviet Union).

Technical program

With eleven sessions running in parallel, the overall technical impressions of any one individual must obviously be restricted to the impressions derived from a relatively small percentage of the sessions, from a number of individual or informal discussions with delegates from other countries, and from an informal compilation of reactions of other American and British delegates.

Approximately half of the papers were classified in the Theory section, with the others divided between Applications and Devices. In the following paragraphs, I devote myself exclusively to the Theory category.

The primary interests (with little recognizable distinction from country to country) probably divided roughly in the following directions: (a) Adaptive and optimizing systems —60%; (b) Non-linear problems—20%; (c) Multi-dimensional systems—10%; (d) Other areas of theory—10%. Certainly by far the strongest interest was in the area which Americans often call adaptive- or computer-controlled systems, but which was divided for the congress between 'Optimal Systems' and 'Adaptive Systems' (a logical division because of the differing design philosophies which are encompassed, but a division which the Committee obviously found difficult to implement since there was considerable overlap). In addition, a number of the papers in other areas were primarily concerned with adaptive techniques.

In the area of adaptive control, primary concern of the Russian effort as reported at the congress seems to have focused on the theoretical and experimental investigations of the various techniques for the automatic, real-time search for an optimum operating condition. Feldbaum and Lerner, at the Institute of Automatics and Telemechanics, have constructed experimental equipment to adjust automatically twelve control variables in order to realize optimum performance, defined in terms of a minimum settling-time after a step disturbance, for example. The criterion may be economic or may relate to product quality, provided that the n-dimensional surface over which the optimum is sought does not include secondary minima (if such minima exist, additional large perturbations must be introduced, with a consequent significant increase in the already lengthy search time).

A variety of search techniques have been investigated for the solution of the non-linear programming program. Successful, albeit slow, results have been achieved on the basis of a steepest-descent approach to the optimum: at each point, partial derivatives of the response time (or other criterion function) with respect to each variable are calculated from trial increments along each axis. When the operating point approaches the optimum, the equipment is switched to a search on the basis of the gradient method. Along the boundary of the n-dimensional space, the standard, zig-zag method of solution is used, although investigations have been made of the mechanization of a smooth run along the boundary to an optimum point.

In addition to extensive work of the above nature (including the efforts by Ivakhnenko to apply this theory coupled with the work on the invariance principle) a major effort is apparently being made to investigate the engineering significance of the work of Pontryagin and his associates on the maximum principle in the theory of optimal control. Lerner is actually constructing computing equipment to implement the Pontryagin solution, although not as a real-time solution of the optimization problem. In this approach to the problem in which Bellman has applied his dynamic programming methods, the solution is in the forward direction (in contrast to Bellman's solution, which works from the optimum condition back toward the initial state). Although the mathematics are relatively difficult, the basic concept is quite simple: on the basis of an arbitrarily chosen parameter, we calculate an optimum trajectory in phase space from the initial state and observe the amount by which this trajectory misses the desired terminal state. The arbitrary parameter is then altered, and a new trajectory determined. The process is continued until the trajectory calculated falls sufficiently close to the desired terminal state. Although the calculations are relatively complex, the method possesses the marked advantages (compared to the dynamic-programming solution) that we remove the unrealistic constraint that the trajectory traversed must pass exactly through the desired terminal state, and that the computations required are very much less.

Throughout the sessions on adaptive control and many of the discussions, other contributions were presented by a large number of Russian participants as well as delegates from other countries. The primary emphasis was consistently on the design of adaptive systems closely related to real-time realizations of optimizing control—systems in which an analytic performance criterion can be established, whether such a criterion be phrased in terms of dynamic performance or in other terms indirectly associated with dynamics (such as an economic measure of system quality). The discussions of adaptive control, in which only a roughly-defined system-performance is demanded in the presence of wide variations in process dynamics or disturbing signals, has apparently been of recent interest to Tsypkin, Goldfarb, and others, but the only discussion of these problems were in the technical papers presented by primarily the American group. In the reports by Li and Gibson, for example, discussion and questions from the Russian delegates consistently interpreted the work in terms of the extremum problem.

In the areas of stability analysis and the effects of random disturbances on adaptive system performance, the Russians seem to have studied the problems in greater depth than people in other countries. The stability of self-adaptive systems working on the optimizing principle has been studied in a variety of simplified cases, and the majority of the rather extensive experimental work reported has included detailed studies of the effects of random disturbances.

The importance placed on adaptive control is perhaps best exemplified by several specific aspects of the congress. The sessions on optimization and adaptive systems included 32 papers and 110 formal discussions (submitted in writing for inclusion in the Proceedings of the Congress

to be published in the late fall of 1960)—by far the largest number of formal discussions associated with any group of sessions. The all-day session on June 28, scheduled from 9.30–5 with a two-hour luncheon break, actually lasted until nearly 8 p.m. with only a brief break for lunch; in both morning and afternoon sessions, a large number of the audience were unable to speak because of a lack of time. Finally, the significance attached to adaptive control is indicated in the opening remarks of Trapeznikov, in which he listed three 'major scientific and engineering problems facing automation at the present stage of development': (1) Optimizing systems, with particular emphasis on the synthesis of simple systems approaching optimal. (2) Adaptive and self-learning systems. The study of principles involved in the design of automatic systems which handle such problems, as well as their theory and calculation are among the most urgent tasks facing automatic control theory. (3) Study of the principles governing the design of automatic machines which supplement or supplant the human design engineer.

In other Theory sessions, interest focused, of course, on non-linear problems (e.g., the determination of Liapounov functions and the investigation of the validity of the describing-function techniques), on sampled-data and discrete systems, and on the design of multi-dimensional systems. In the latter category, a major Russian effort is clearly on the exploitation of Kulebakin's work on the invariance principle (the general formulation of the conditions under which disturbing signals do not affect the response in multi-loop, multi-dimensional systems). The work seems to represent the mathematical generalization of a variety of specific schemes utilized widely in the United States and Britain for realization of improved performance (with the associated advantage that such a generalization leads not only to a unified theory, but also frequently to the logical synthesis of novel configurations and systems). The paper by Kulebakin and the accompanying contribution of B. N. Petrov generated by far the lengthiest discussion I heard during the week.

Thus, the technical portion of the congress was marked by extensive discussions; the congress as a whole was notable for the friendliness which prevailed among the delegates and the willingness (and even eagerness) on all sides for both formal and informal exchanges of information and discussions of current work. The formal papers, in most cases prepared more than a year in advance of the meeting, were primarily significant as indications of the directions of interest of control engineers in the participating countries. The primary contribution of the congress was unquestionably the opportunity provided for meeting control engineers from other nations on an informal basis.

J. H. Westcott expects a great leap forward from the congress springboard. Meanwhile—

OVERBOARD WITH THE FREQUENCY RESPONSE

IT HAS BEEN A MEMORABLE OCCASION, THIS FIRST CONGRESS of the International Federation of Automatic Control. Since 1945 automatic control has rapidly become one of the recognized technologies. In 1951 we had the famous international gathering at Cranfield, perhaps the first major international gathering in this field. In 1957 at the Heidelberg conference on 'Regelungstechnik' the foundation document of Ifac was signed by representatives from about fifteen countries. Now, after this Moscow conference, conceived in such proportions as to justify its description as an *international* congress, attended by about 1100 delegates and served by a three-inch-thick volume of preprints of over 280 papers, Automatic Control may truly be said to have arrived.

What can we say about the technical content of this congress? That, too, was as remarkable as the size of the conference and the expansiveness of the arrangements. The Russians in particular seem to have put their best foot forward. Automatic control for them is a subject to be taken seriously; in this country we still seem sometimes to be a little bit in doubt about it. Is there really anything in all that abstruse mathematical analysis? Has control engineering any real future? Those are questions you will still find asked here by influential people. For an answer read the Ifac Congress proceedings: but allow a fortnight to do it in! From the point of view of the 'western' delegates the Russian papers were a sudden unfolding of Soviet activity in this field. At the Heidelberg conference, where six distinguished Russian scientists working in this field were met face to face for almost the first time, it was evident that western work was studied by them in great detail. The familiarity with names and published works of western engineers revealed by these men was quite surprising when one considered the almost total ignorance in the reciprocal direction. This was in 1957. Since then a good deal more information has seeped across the divide about activities in the Soviet sphere. But even today we are relatively ignorant of what has been going on there; and now, at this conference, when we have suddenly been presented with the latest results of work that has been going on for a number of years, the effect is rather startling. We shall need to do a bit of back reading in order to find the origins of developments which are new, and which in some cases (particularly with theory) cannot be readily understood, let alone assessed, until this reading has been done. Perhaps a year from now will be a good time to give a more considered opinion on the value of the new ideas we have heard and do not for the moment recognize as familiar. The abundance of material presented at the congress was one of its drawbacks. During the course of the five days of official technical sessions (there were many unofficial ones; quite as important to the success of the congress as the formal ones) it was only possible to hear the discussions on one tenth part of the papers,

even by the most assiduous attendance at the sessions (which few delegates attempted). Nevertheless, even from this small cross-section a broad impression percolated through to delegates; the impression that a great leap forward in the technique of control is imminent. It is not possible to say at this stage what precise form these developments will take; even much of the practical detail of the theory remains to be worked out, but the message of revolutionary change in methods of systems design was clearly implied in the proceedings, and nowhere more clearly than in the sessions on the theory of automatic control. Here one got the most extraordinary impression of a burgeoning of extravagant growth. The rate of growth is so great as to give the impression almost of panic—panic lest the other chap should reach over the wall first. One senses that the prize to be won is not a slight one, and that it could yet go to the steady tortoise rather than the exotic hare. Some of the growth is perhaps too weedy to survive till tomorrow, and he would be a bold man who would point to any one development today as the certain winner, but it is worth briefly surveying the field of potential starters. We leave posterity to award the prizes.

The essential novelties of theory can be conveniently discussed under three main headings: (1) Variational methods, (2) Stochastic methods, and (3) Theory of adaptive systems.

Variational methods

One has come to accept frequency response methods as the central established technique for the design of control systems. Even with the introduction of statistical techniques one has still had the reassuring resort to spectral density functions which are nearly related to frequency responses and therefore basically familiar. But the frequency response method is being cheerfully dumped overboard in the first two of our categories of new methods; perhaps most decisively in the first group, the variational methods. With these methods there is detachment from the idea of transfer functions between one variable and another. Transfer functions, it is argued, are a means to the end of minimizing error between one quantity and another, and that end is not the crux of the matter. The real crux is to maximize a properly-chosen performance index, or, if you prefer, to minimize a cost function. Whether one prefers to maximize or minimize, the methods proposed are essentially the same; somehow to continue to adjust a sufficient number of manipulable variables or parameters so as continuously to satisfy an extremum of the index. A great deal of interest centres around the 'somehow'. By no stretch of approximation can the problem be considered to be a linear one (over goes the frequency response!). On the other hand, to be of interest in automatic control the problem is definitely a dynamic one. The Russians have been famous in the past for their interest in and contributions to the theory of non-linear mechanics. This would be their natural starting point, but the subject is recognized to be beset with the most intractable difficulty. How, for the purposes of automatic control, can the difficulties be overcome? By recognition of two factors: (a) that the inputs may be satisfactorily described in statistical terms, and practical answers to control problems given in these terms, and (b) that the resulting complicated calculations lend themselves to working out on digital computers and can possibly be completed rapidly enough to be practical in computers envisaged currently. An interesting paper by Boltyanski *et al* gave mathematical expression to this idea and was clearly based on much prior work (notably that of Pontryagin and his students) on optimal control. The Americans on the other hand have made a particular mark in the serious study they have made of the factors contributing to business decisions, and they have always been most ready to employ machinery for the accumulation of data on which to base these decisions, and to use data-handling equipment and computers to calculate the odds. They too have asked the question: how can the difficulties of analysis associated with a non-linear dynamic system be solved? It is natural that they should have regarded this as a multi-stage decision process and devised a technique of analysis described in conceptual outline in a paper by Bellman (the scion of this technique) on dynamic programming. Superficially the two approaches have little in common, but it is of great interest to find a paper by Rozonoer demonstrating the equivalence (which had been realized in Britain) between the Pontryagin optimal control and the Bellman dynamic programming methods. From an analytical point of view the antecedents of the Pontryagin method are more clearly seen as founded in the classical dynamics of the turn of the century (see Whittaker, 1904) and the Hamilton-Jacobi partial differential equations. There is a change of emphasis in the application of this analysis to automatic control in that the theory of optimal systems is concerned with control action, which we may define as the velocity of physical points of the system, while analytical mechanics is concerned with co-ordinates, their derivatives, and time. These methods in their full generality involve a truly mammoth quantity of calculation. Several papers were presented which sought to reduce this sheer weight of computation. A paper by Merriam outlined one promising method of avoiding the flooding procedure associated with dynamic programming, by using parametric expansions. A paper by Bertram *et al* illustrates the direct use of the calculus of variations in a terminal control problem. The full rigours of an optimal control arise when the problem cannot be resolved at a single blow and has to be broken up into time intervals that may be regarded as independent. The dynamic programming formulation, as opposed to the calculus of variations, then avoids trial procedures associated with non-linear Euler equations when both boundary conditions are fixed. In any case, an explicit Euler equation cannot be written when saturation occurs, and this is a genuine practical restriction in process control work. Actually the Russian interest in pneumatic switches is reinforced by the fact that the controller specified by the Pontryagin optimal control is most easily expressed in terms of a switched function.

Although I have described these particular developments as work starting from independent viewpoints in separate countries, it would be wrong to suggest that the contributions to advance are being made on this strictly national basis. There is a climate of activity and opinion in this field, and it turns out to be an indivisible one. One of the notable features of this congress was that this fact has been made even more clear, and one hopes that nationalistic boundaries in the future will be even less obvious in what ought to be treated as a universal study.

Stochastic methods

The reader may be understandably wondering where British contributions come into the picture, and one would hazard a guess that it is under the heading of *Stochastic methods* that the most significant British work is to come. Once one has accepted the need for a comprehensive performance index in assessing control systems, it is almost a truism to say that variational methods will be needed, but the conjunction of statistical analysis with variational methods brings in its train special problems associated with calculating the probability distributions of signals at various points in the system; and, in particular, since the

system is a dynamic one, the manner in which these vary with time. Since frequency functions have had to be abandoned, at least in the first stages of analysis (there is reason to believe that they may well be needed at a later stage, so that further efforts in this direction are not wasted!), something has to take their place as a means with which to calculate dynamic responses. System relationships being essentially non-linear, there is a very plausible case for the view that probability density functions will fill the gap. The basic paper of Barrett discusses a method of analysing the behaviour of dynamical systems under the influence of random disturbances, and shows that exact solutions can sometimes be obtained to the randomly disturbed non-linear control system. The difficulties associated with solving these problems are twofold: first, formulating, in terms of a properly chosen state-vector of the system, the partial differential equations which define the time-dependent probability function; and secondly, solving these partial differential equations for the function itself. Barrett gave a number of examples indicating clearly enough the analytical difficulties; Fuller, dealing with relay control systems, used Barrett's method to get solutions with random inputs; Ruina gave an example in greater practical detail of an automatic tracking system in which the probability of error is worked out for the linear case as a distribution function using the Fokker-Planck equation (usually associated with the diffusion effects of Brownian motion). For non-linear examples in this paper, resort had to be made to a digital computer used on a cut-and-try basis. The problem of devising accurate numerical methods for solving partial differential equation of the Fokker-Planck type is a live one. It is not obvious that digital methods are the most appropriate, and two papers presented by Kuei-Chuang *et al* and by Karplus describe analogue-discrete methods of computing the solutions to partial differential equations, the latter paper being particularly concerned with solving transient field problems including those involving a wave equation.

On this theme of the randomly disturbed control system, a number of variants were given which can rightly claim to be based on stochastic methods. Typical of these is the method given by Pugachev in which he works out an algorithm based on correlation functions for various criteria, based on probability. A paper by Lubbock on Zadeh Class 1 non-linear optimum filtering systems is of interest, and leads to a particularly simple method of synthesis in the form of parallel-path networks. A paper by Prasad makes use of similar techniques for the mean square optimum extraction of signals, whereby the filter coefficients are directly obtained from measurements on random staircase inputs. Also from the Cambridge school is a further contribution to the systematizing of the design of linear mean square error systems satisfying an r.m.s. constraint, with the presentation by Coales *et al* of charts and tables for a standardized form of input power spectrum.

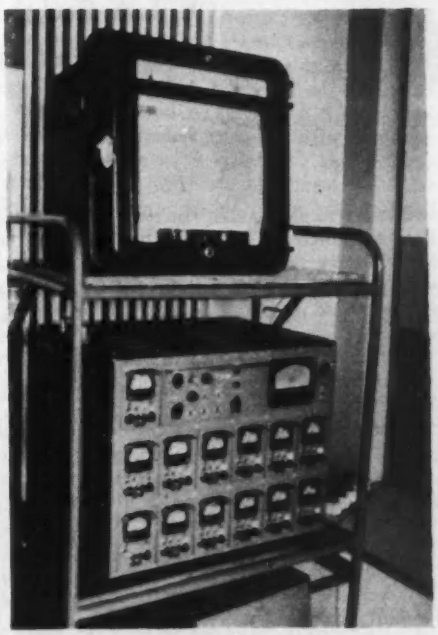
Adaptive systems the dominant theme

One could almost say that the dominant theme of the Congress was *Adaptive systems*. A surprising number of papers had something to say about it. It is, so to speak, the popular thing of the moment, and not to have views about it is inadmissible. One has a very wide choice as to method, running through the whole gamut from pure theory to crossbred practice. Comment is consequently made hazardous, and underlying it all is the nagging question of whether such schemes are economically justified. One feels confident that further development of the methods described in the previous two sections of this article will make practical evaluations possible on this important question of economic justification. Perhaps this consideration, as much as anything, is why the stakes are so high for getting there first.

It is easy to sound complicated when talking about adaptive systems, but very few authors succeeded in making the subject sound simple. Top honours here go to two authors, one American, one Russian. To some extent these two papers are saying the same thing, but in ways that are characteristic of the approaches of two different groups. Widrow on adaptive and sampled-data systems was delightful. Whether his terminology of 'supervisor's supervisory system', 'supervisory system' and 'worker system' had quite the same clarity for Soviet ears, with its shades of machine-like personality cult, we do not know; but his simple explanations, illustrated by signal flow graph, made an immediate common-sense appeal in a brief but illuminating paper. Feldbaum, on the theory of automatic probing, required a little more determination, and in western engineers rather more background knowledge of the references in a terse text. The paper was concerned with various modes of operation to maintain a performance index at an extremum when the process is disturbed by random interference, and when performance-index evaluation is subject to random errors. The necessary measurements are made discretely. The author gives a theory for finding the best number of measurements at given time intervals before each operating step, in order that the mathematical expectation of probing time shall be a minimum for various degrees of interference intensity. If you had to read that sentence twice to get its meaning, the same would probably go for the whole of this paper, but the outcome has the clearest practical implications for the efficiency of such probing action: it lies at the heart of adaptive processes. Practical realizations of these probing techniques are described in a paper by Stakhouski *et al* who worked under Feldbaum's supervision.

Another paper of interest in this category is the one by Margolis *et al* on a parameter tracking scheme for matching a simulated model to a system using a quadratic

Much interest was shown in this rig at the Institute of Automatics and Telemechanics. It was described as a device for optimizing a twelve-variable system



criterion based on the sum of error and its higher derivatives, suggested (but not exactly explained) by steepest-descent procedures. This reveals that linear methods of analysis can come into problems of this type at the slightest provocation, and the parameter tracking-loop is designed on a root locus basis. Parameter tracking of this sort represents an apparatus solution to the important problem of parameter estimation, a subject also discussed in a paper by Westcott. Another parameter adjusting scheme was described by Andrew. In this the flow to a four-capacity plant is controlled at the input in an attempt to maintain level in the final capacity in the face of random output fluctuations. The level in each capacity is monitored and related to the control function through parameters whose values are determined by correlation methods, the results being obtained by simulation of the system on a Deuce digital computer. This study, quite sensible in its way, indicates the shortcomings of much work that is being undertaken on adaptive systems, and that is the impossibility of knowing in what direction any improvement is to be sought outside the particular circumstances of the particular experiment. That is not a reflexion on the value of this particular piece of work (one could have selected several others), but rather a comment on the techniques such as the Pontryagin maximum principle or the Bellman dynamic program. These methods do lend themselves to the setting of standards for such systems, or even *à fortiori* further extension of Barrett's work, which would be directly applicable to the assessment of such schemes.

A number of adaptive systems having particularly simple realization were described. One might mention that of Gibson, based on a simple-rule steep-descent procedure using a digital computer for the control of the time constants of a lead-lag network; or again, the paper by Braun *et al* which matches a model to the system using orthonormal functions and employs the model for prediction to control the system. A more sophisticated procedure of this type was described in general terms by Eckman in what he called the sub-system approach to optimizing control. Chinchinadze had yet another approach invoking game-theory ideas, which, through the use of Monte Carlo searching, eliminates positive-entropy solutions as a form of learning process.

Although there is a rich diversity of possibilities here, the systems that have been described in the conference proceedings have sufficient in common for the essential attributes of an adaptive system to emerge; they are three, as follows:

1. A system for evaluating the underlying statistical parameters of the disturbances, which decides the basic pace of adaptation desirable in the system and so the scale of time interval over which the system may be considered as unchanging or in equilibrium.
2. A means to assess continuously the bearing that the values of current measurable variables will have on the comprehensive performance index.
3. A means to assess and effect the necessary control action of manipulable variables which will lead to the optimal value of performance index in the current era.

The message is clear enough

Taking an overall view of the theory section of the Congress, one cannot help feeling that we have come a long way from the day when the frequency response was introduced as a method to avoid the difficulties associated with the calculation of step responses in the design of servo-mechanisms. The mysteries of instabilities were settled by avoiding encirclement of the $(-1, j0)$ point and quoting Nyquist's famous paper, which few could follow (or even bothered to read) because it referred to some obscure mathematics called function theory. When eventually the necessity to understand the stuff was faced, all manner of advances in the art were made. Today we stand once more at such a point. This time references are being made to Brownian-motion disturbance of general dynamical systems. The message is clear enough; back to wet towels and black coffee, back to the proceedings for 1905. The effort will surely be worth it, but one wonders who will make it when the starting qualifications involve access to digital computers and pilot plants, in addition to possession of a pound or two of rather unusual grey-matter.

R. J. A. Paul thinks that existing mathematical techniques are being underplayed, but finds that there is now a firmer basis for

DIGITAL COMPUTER CONTROL

IT IS IMPORTANT TO EMPHASIZE THE FACT THAT MY REMARKS about the conference are personal. They are based on attendance at relatively few sessions, and on informal discussions with other delegates. A selection of theoretical papers is briefly discussed below. I accepted coverage of these main topics as a specific task, so sharing the work with Dr. Westcott. The selection does not necessarily represent my assessment of relative interest or importance in the congress as a whole.

There seemed to be a preponderance of purely theoretical papers (a total of 140) at the expense of more erudite engineering applications. I felt that existing mathematical techniques had not been exploited to their best advantage in the field of control engineering and there seemed to be a wide gulf between theoretical considerations and design techniques pertaining to overall systems and components. Nevertheless many of these papers were of fundamental importance, and I was particularly impressed by the papers dealing with the Theory of Invariance and Multivariable Control Theory. Discussions on the whole were rather disappointing, and the requirement for a formal written contribution, to be submitted in advance, restricted to some degree the amount of spontaneous discussion. Moreover, in some sessions, discussers used the opportunity to present another paper, rather than consider in a critical manner the paper presented. One fact was obvious; that the Russian delegates had found time to peruse the relevant papers in some detail. Disappointing to me was the fact that there were few occasions on which to discuss topics in an informal manner with the Russian delegates. The main contact was obtained during the technical visits.

There is no doubt that the Russians are putting a large amount of effort into the field of automatic control. Although there is not much evidence as yet of practical and economic realization of optimum systems for process

plant, it would be foolish to suppose that this deficiency will not be rectified to some extent in the near future.

It is difficult to spotlight, without further reflexion, the major trends in the theoretical aspects, with which this review is mainly concerned. The following might serve to indicate major topics, in addition to those already noted.

Further development of linear statistical theory and synthesis.

Application of statistical theory to non-linear systems.

The Maximum Principle, i.e. the optimum design of a control system to minimize the expenditure of energy in performing a required task.

Dynamic Programming, i.e. the study of control systems as multi-stage decision processes, with emphasis on methods suitable for high-speed digital computation.

Development of the theory of discrete systems (sample-data and relay systems).

Theory of self-adaptive systems.

Over fifty papers were presented on computing techniques, transducers, data handling and components of systems. I was particularly interested in the computing techniques, and have selected some for description below.

In summing up the congress, I would make the following points. The significance of the Russian contribution was reaffirmed. There was a lack of down-to-earth engineering applications of optimum control theory, and the gulf between theory and practical realization seems to be widening. The mathematical content of some papers may be such as to appal the engineer, but it is comforting to reflect that the end-results of a control system or process plant can be specified in simple terms. On economic grounds, the practical realization of a theoretical technique is the important thing, and this aspect deserves more attention by engineers in the future. In the field of process control, the application of sophisticated control theory must be delayed in many cases until a deeper understanding is obtained of the process itself. As I have stated before, it is difficult to assess at this stage the relative significance of the main theoretical themes, but it would appear that the use of digital computers to control process-plant to give an economic optimum result is more firmly established on a theoretical basis.

Continuous linear systems

J. Marsik (Czechoslavakia) read an interesting paper on a linear system with time-varying parameters, with a controller comprising conventional integral or proportional-plus-integral terms followed by a transfer function which is the inverse of the control-system transfer function. Unfortunately experimental results are not included as an indication of the success of this approach. There would appear to be some restrictions or realizability conditions, and it will be interesting to read of further work on this.

P. S. Buckley (U.S.A.) discussed various techniques for the compensation of processes with dead time. He made comparisons between conventional integral controller, feedforward techniques and the use of a Smith linear predictor. Experimental verification of theoretical results is included by considering the control of a liquid-mixing process. The Smith-type linear predictor is shown to give the best results.

The invariance principle (i.e. independence of the controlled magnitude in respect of disturbances acting on the controlled member), was discussed by V. S. Kulebakin (U.S.S.R.). Analysis is simplified by linear approximation with particular reference to a plant characterized by two co-ordinates. One practical realization of the theory is to measure the external disturbances acting on the controlled object and supply the information regarding these disturbances in a certain form to components which react on the regulator system. Another paper by B. N. Petrov (U.S.S.R.) dealt with the application of the invariance principle to linear and non-linear systems, dwelling on realization conditions in some detail. Active work is being carried out in the U.S.S.R. on this topic, which appears to be of primary importance.

Continuous non-linear systems

A method of static analysis of non-linear systems, comprising elements with two inputs (e.g. electronic or pneumatic valves), was described by A. Macura (Poland). Techniques are presented for splitting complex block diagrams into simpler ones. A two-input element may be transformed into two one-input elements, and this technique may be used to simplify and synthesize the static performance. It appears that the method could be extended to the transient analysis of certain non-linear systems and this would increase considerably its effective use.

J. C. Gille and P. Decaulne (France) presented an extension of the describing-function method for the study of systems with one non-linear element. Three types of non-linearities are discussed in this paper. The conditions for instability of the forced oscillation and for jump effect are determined by the relationship of the transfer locus of the linear elements to the envelope of a family of circles characterizing the non-linear element.

In a paper entitled 'Gain-modulated control systems', J. C. West (U.K.) considered the parameter changes necessary to achieve an error power as a percentage of power input of a stationary random signal. He used a second-order linear system and one with a torque saturation to illustrate the method of determining necessary parameter-changes, which he calls *gain modulation control*. The gain-modulation-element output signal is in general a function of the input signal and another modulation signal. Separation of variables is suggested by using equivalent gain techniques as an approximation. The design of the element can then be achieved by the use of a multiplier. This is an interesting paper as it spotlights a basic concept in the form of adaptive system considered, and paves the way for further work. The discussion on the paper did not do justice to it.

Other interesting papers included one by Popov (U.S.S.R.) who considers the design of non-linear systems by using the method of harmonic and statistical linearization. Systems with two non-linearities are considered and several criteria presented. Syrk (West Germany) described in a practical manner the control of the effect of saturation in a process control by an extension of the describing function. Oldenburger and Nakada (U.S.A.) extended the work published by Oldenburger and Liv in 1959, by considering the application of a stabilizing signal to a generalized control system with one non-linearity, to remove self oscillation. The determination of the required periodic signal is given and the method is illustrated by considering a system which includes a limiter form of non-linearity.

Computing techniques

A method was described by V. V. Solodovnikov *et al* (U.S.S.R.) for statistical analysis of non-linear control systems. The authors detailed a specialized analogue computer (called a synthesizer) capable of solving Fredholm equations of the first kind. The solution is obtained by solving iteratively a set of approximate algebraic equations. An experimental model has been constructed and is intended for use as part of a process control system. The synthesizer is fed with the random wave-forms of input and output of the system and produces the impulse response function of the system. The time required for the solution is 10–40 sec, and accuracy is in the range 5–10%. During the discussion several speakers were unsuccessful in their attempts to get more detailed information

about the apparatus. The use of a digital computer to solve correlation functions was also described.

In the delay-line synthesizer (d.l.s.) the unit-impulse response or weighting function of a linear system is synthesized from a sequence of pulses $h_1(t)$; $h_2(t)...h_n(t)$ delayed with respect to the input of times t_1; t_2, t_n respectively when the input to the delay line is unit impulse function $u_1(t)$. The output of the synthesizer is of the form $h(t) = a_0 u_1(t) + \sum_{n=1}^{N} a_n h_n(t)$. The coefficient a_n can be adjusted between limits ± 1 and so the device acts as a versatile analogue computer. The paper by T. P. Goodman (U.S.A.) describes the use of the d.l.s. to determine a dynamic model of a linear system subject to random inputs. The equipment is an extension of Reswick's earlier work. The design procedure for determining the *RC* delay line with optimum overlap between successive impulses (tapered delay) is given. During the discussion several applications were outlined.

M. L. Morgan (U.S.A.) told the congress of a computer using tele-deltos paper as a representation of the complex plane. Pole and zero locations are represented by feeding voltages to the paper by means of probes. Two sheets of paper are used, one for plotting the logarithmic amplitude contours and one for angle contours. The machine can be used for root plotting, root-locus plotting and frequency-response analysis. The motion of the probe assembly is directly coupled to a stylus on a plotting table which plots the required contours. This computer is to be marketed under the name E.S.I.A.C. at a cost of about $10,000. During discussion, I questioned the possible accuracy, particularly with regard to the consistency of the paper, but precise figures were not available.

A method of synthesizing functions of one or more variables, described by S. A. Ginsburg (U.S.S.R.), is based on a piece-wise non-linear approximation. It is claimed that the method can be extended to functions of three or more variables. The determination of the logical networks required would obviously be a lengthy process. During the discussion, Paynter (U.S.A.), stated that similar work had been carried out in the United States by Philbrick in 1950. I found the paper rather difficult to follow and the discussion was not very informative. The results obtained from this application of mathematical logical synthesis are extremely important, and the paper deserves a more detailed study.

'A discrete-space discrete-time computer', the subject of a paper by W. J. Karplus, is a network analyser containing precision resistors and d.c. amplifiers, designed for simulation of field problems including the diffusion equation and the wave equation. The computer is a hybrid analogue-digital machine. Electrical voltages are proportional to field potentials, as in the case of the conventional analogue-network analyser; but the time variable, as well as the space variables, is approximated by finite-difference expressions as in a digital computer. The design is based on an extension of a method proposed by Liebmann in 1956, but differs in that some of the resistors at each node have negative magnitudes. The latter are simulated by means of active two-port networks. The solution is obtained in discrete steps in time. This is a useful paper and the computer should prove its worth in field investigations.

There was wide interest in both the paper by Stakhovskiy *et al* and an experimental model of the system exhibited at the Moscow Institute of Automatics and Telemechanics. The main component of the system is a device which automatically searches for the minimum value of a controlled quantity, Q, with limits on the range of possible search. The output quantity Q may be a function of n input variables and the paper describes a model with $n = 12$. The output is the function $Q(x_1, x_2...x_n)$. A combination of values of $x_1...x_n$ is automatically chosen in an iterative manner to yield the minimum value of Q. It is important that, over the range of variation of the input variables, there is only one minimum value of Q, as otherwise the logic of piece-wise representation is very complicated. Details of the method of search and the logic of switching are described in a paper by Feldbaum published in *Autom. Telemech.* Moscow 19. No. 8. (1959). The model was demonstrated acting as an automatic function generator of one variable, and detailed results are given in the paper. During the discussion it was difficult to ascertain whether the apparatus had yet been put to practical use.

R. J. Redding discovered excellent intentions at the congress, but he is embarrassed by the

GULF BETWEEN THEORY AND PRACTICE

THE ORIGINALLY PUBLISHED MOTTO OF THE IFAC CONGRESS stressed the wide application of theory, the reliability of instrumentation and the effectiveness of process control. In the event the papers in the theory section outnumbered the papers in the other two sections, those on components and applications, and it is easier to assess the trends in research than the state of the practical art.

Further, in considering the practical papers one must bear in mind the context in which each is written. For example, one Chinese paper dealt with a problem of arc-furnace control which is probably insignificant in western practice. Another described a three-term controller based on a relay and heating element integrator. This was designed to meet the limitations of steelworks personnel in China.

A major theme of the congress was the consideration of a process as a whole as opposed to the previous one-measurement-one-loop approach, the goal being adaptive and self-optimizing systems. The immediate aim is an equation describing the performance of the plant in order that a mathematical model or master computer may adjust the desired values of the controllers, thus reducing the

amount of decision required of the human operator. The papers indicate an enormous effort on this theme and the investigations of attendant problems such as interaction between loops and the dynamic behaviour of processes.

Early practical steps towards this goal were indicated in German papers on boiler control by Ergin and Ling, and another by Krussman, who went deeply into the subject of multi-element feed-water control. These investigators use analogue techniques, but many favour the digital computer. However, it is significant that the computing equipment is additional to the conventional process control equipment; a digital computer would change the desired value at intervals (twenty minutes is suggested in one case) and the additional reliability of the combination is well recognized.

Whilst the design of three-term process controllers received little attention, several papers dealt with dead time as the arch enemy of control. A paper by Buckley clearly showed the limitations imposed by dead time and described the improvement resulting from a feedforward technique. One by Quack and Schneider detailed the dead time of resistance thermometers, and another dealt with pure time delay in a fuel conveyor system.

There is little to report concerning regulating units. Whilst there were reports of investigations into pneumatic and hydraulic media, no change in present practice seems indicated, except perhaps a greater use of speed control, several examples of which were reported. This suggests that present loop control elements are considered adequate for the implementation of optimizing and computer control.

The importance of measurement, and, in particular, quality control measurement, was apparent so often in discussions that it is surprising that only one paper was presented on the subject. In this contribution Patient described the automation of sampling and chemical analysis apparatus.

Survey papers describing the achievements and aspirations of a particular industry were very popular and well attended. These gave the opportunity for illustrating the integration of individual processes towards the full automation of industrial production, showing the economic use of both analogue and digital techniques. Dr Foster deals with some of these papers below.

The interest in 'on-line' uses of computing and quality measurements was such that an additional discussion meeting on the subject was held. Unfortunately much of the time available was spent on terminology and endeavours to classify the schemes described by individuals. The breadth of usage of the term 'data reduction' complicated this issue, and it became apparent that steady-state compensation is simpler than the full dynamic compensation which some people consider essential.

To sum up, the congress showed a will to take automatic control of continuous processes far beyond its present state of development and to utilize to the full the capabilities of mathematical tools and machines. However, the gulf between theory and practice, between aspiration and actuality, is embarrassingly wide.

D. B. Foster points out some shortcomings in the Ifac organization, and then finds that

THESE ARE THE PRACTICAL NEEDLES IN THE THEORETICAL HAYSTACK

A FIRST GENERAL EXAMINATION OF THE PAPERS REVEALS TWO aspects which limit usefulness for immediate practical purposes. In the first place the papers are predominantly theoretical in method of treatment, and whilst this may appeal to the academic and mathematical interest the ultimate practical application belongs to 1970 rather than to the present decade. The second aspect is the fact that the papers tend to concentrate on the long-term control problems associated with the continuous processes of the steel, chemical and oil industries, and the total scope of such processess is probably not more than ten per cent of total industrial activity, including transport and distribution. One wonders: where are papers relating to automatic warehousing, to improved transport signalling systems for road and rail traffic control, to the control of batch chemical processes? And where are the papers related to automation for the smaller industrial units—or is the whole subject a matter for titanic organizations, totalitarian or capitalistic?

A further point which strikes the practical man is the almost total absence in the papers of reference to interesting developments in measurement and transducers. Where are papers on improvement in the performance of load cells, in the use of isotopes for the measurement of materials, in the development of mass-flow meters? Also, what about automatic inspection for manufacturing industry? And automatic selective assembly for motor-vehicle engines? Or even just automatic assembly!

One therefore asks oneself two questions. First do these papers, in general, represent the sort of development which is going to revolutionize industry and give us the twenty-hour week that will permit the Russians more time to write ballets, the Americans to play golf or the British to put more time into the back garden? The answer in my opinion is simply 'No'. The second question which arises is whether Ifac is an appropriately constituted body to be responsible for the technical aspects of practical automation. Perhaps Ifac does not claim to perform this task, and is tending to have the job thrust upon it: but if it does aspire to don the full automation cloak, then it must broaden its interests and recruit some production engineers into its ranks.

In his introductory paper on 'Automation and humanity' read to the general assembly at the conference, Academician Trapeznikov made it clear that Russian objectives in control engineering are essentially practical, and that the Soviets will not be satisfied until all industrial and distribution processes are highly automated. A great deal of practical work to this end is going on, and emphasizes the need for a rebalancing of activities by members of Ifac, towards practical achievements.

Taking the above introductory remarks into account as

a background, and to some extent as an apologium, one now looks at these 300 or so papers, occupying four volumes and extending to over 2000 pages, and tries to find the practical needles in the theoretical haystack. Now, out of all these papers, there appear to be not many more than a round dozen which give novel, interesting and practical information, and five or six of these are from British sources; but let us first look at six practical papers from foreign sources.

Automated irrigation

The growing pressure on the food production resources of the world, particularly in arid climates, necessitates the use of irrigation systems—and the most effective use for water economy. This field is a promising candidate for automatic control, and several experimental installations are being developed in the U.S.S.R. Such schemes depend upon regulating the flow into and out of a progressively branching system of local locks or reservoirs. Level and flow rate are the measurement problems in such a system, and the actuation features will be the opening and closing of hydraulic valves and sluice gates. Whilst there are many possible technical solutions to such a control problem, the economic aspects are very important, particularly with respect to minimization of electrical control-power and transmission-line costs, and it also has to be borne in mind that existing installations are usually manually operated but already have telephonic communications.

In general, the new U.S.S.R. systems described by Gankin make the maximum use of locally available hydraulic heads in the lock systems for control power, and the central control system uses cycling telemetering both for measurement and for set-point control. Such small power as may be required for operating slow-moving valves, limited often to a few watts, is transmitted over the telemetering lines. Use is made of local loop control to achieve constant flow characteristics, and this depends on floats which measure the pressure head in reservoirs and open valves as the head is reduced. The telemetering equipment cycles round the various flow and level-measuring points, and compares the corresponding electrical currents with set-point currents in a bridge circuit, raising an alarm in the control room if the permitted deviation is exceeded. The deviation is given by a single meter, common to all the sampling lines, and the human central controller takes appropriate corrective action. The total central control equipment for a 35-position system is contained in a single instrument about three feet long by one foot high. At present the system uses telephone relays but is now being developed on a solid-state-device basis.

It is claimed that such a system reduces staff on an irrigation system by a factor of three, and taking this into account together with reduced housing costs the installation will break even in three to five years, quite apart from water savings due to better control. It is considered that centralized control permits the design of a more economical water distribution system, and that the overall initial capital cost may be less than in manually controlled systems.

This paper is typical of the practical way in which the Russians are tackling important problems on a very down-to-earth and common-sense basis, to achieve maximum value for money and development effort.

Human hand as a feedback system

Tomović (Yugoslavia) had a refreshing outlook towards feedback systems at large. His paper was mentioned briefly in last month's CONTROL, but I should like to refer to it again. He points out that *negative*-feedback systems are by no means the only possible forms, and he quoted the example of gripping by the human hand as requiring essentially a *positive*-feedback system. In general, he recommends us to try systematically to figure out all possible forms of feedback systems, and try also to see what control features these systems might have. Tomović considers that the production of automatic hands, which really *look* like hands, is an important target both for general automation purposes and also to provide more effective artificial limbs for the maimed. He has already gone a long way towards the practical achievement of this target. His artificial hand, which is being developed in collaboration with the Institute for Anatomy of the Medical Faculty in Belgrade, consists of a skeleton of the actual bones of the hand with two forms of actuation. The first is an elastic system in tension, which has the effect of tending to keep the hand open in the non-operating condition. The second is a wire system operated off an electromagnetic solenoid, which closes the hand on supply of power to the solenoid. The actuated skeleton is enclosed in a rubber glove filled with an elastic porous material, such as sponge impregnated with carbon dust of the type used in carbon microphones. This second system is used as the sensing device since, as the hand closes under the force of the electromagnetic solenoid operating the wires, the effect is to compress the sponge and carbon granules and lower the electrical resistance through the hand. This effect is picked up from film electrodes made by electroplating the back and front of the inside of the rubber glove.

This system is very close to the characteristics of a real hand because the sensing of closure by the carbon granules gives an electrical signal which is proportional to gripping pressure, is also proportional to gripping area, and can be made appropriately non-linear in that it can be arranged to saturate. This sensing signal is applied as positive feedback to the actuating solenoid, and gives a natural gripping action with saturation. At the moment the artificial hand is controlled by operating a switch in the solenoid circuit so that the hand closes under positive-feedback control, but consideration is now being given to refinement of this decision technique. Solutions are also in hand to extend the same sorts of principles to individual finger control.

This development, which is practically demonstrated by the ability to hold a delicate wine glass, appears to be of the highest practical importance. British medical science please copy!

Punched-tape-controlled lathe

Bingen and Vronan (Belgium) described the operation of a multi-tool lathe, intended to be used for machining small lots of shafts and parts which require both external turning and internal boring. There are three carriages; one is for copying, another for cylindrical and conical turning, and the third has a turret with six tools.

All displacements of the three carriages and the spindle speeds are automatically controlled from punched tape in a control cubicle. The equipment in this cubicle comprises: a photo-electric tape reader, a decoder, a sequence controller, the numerical control and positioning circuit, the control equipment for the copying carriage, the spindle control circuits and the protection devices. Additional equipment is a standard teletype-keyboard-operated encoder for making the punched tape.

Numerical positioning circuits have three special features: (a) they form a servo-system which alternatively acts as a velocity and a position servo-loop, (b) they use simultaneously analogue and digital circuits, (c) they are entirely solid-state, being made up of transistor switches and magnetic amplifiers.

The carriages are driven at constant speed to give regular turned finish, and this speed is related to tool feed and spindle speed. During the main part of the travel the

servo-loop is connected as a velocity loop, but during the last millimetre of travel the carriage is braked and the servo-loop is converted into a position loop. The error signal between actual and desired position of the carriage is determined by three synchro-transformers in series.

The machine is capable of three types of operation. Firstly as a completely programmed system from punched tape; secondly as a semi-automatic machine but controlled from a manually operated keyboard; lastly on a fully manual basis by potentiometer settings.

Automation of electrical drives for new steelworks

Typical latest practice in steel mills in the U.S.S.R. was described by Brozgol, and record figures were claimed for annual output per mill: 3·5 million tons for blooming mills and 1·3 to 1·4 million tons for rolled-girder mills. The drive systems used in these works are mass produced and make maximum use of standard electric motors. Extensively integrated automation systems employ relatively few standard sensing devices such as photo-pickups, load relays, synchros, tacho-generators and track switches.

Main drives. In general, mercury arc rectifiers are the basis for speed control of motors, feeding the armatures on the non-reversing-mill main driving motors and also the field circuits for the main driving motors on reversing and non-reversing mills. Three grid control systems are used to control the mercury arc rectifiers: (a) with static-phase regulators and peak chokes giving a control angle up to 150° (for rectified field supplies to the main motors of reversing mills), (b) with half-wave magnetic amplifiers with control angle up to 90° (for control systems of the main drives of non-reversing mills), (c) rectified excitation of generators and motors, for the main driving motors of the blooming and girder mills.

The circuit systems employed ensure reversing control, three operating speeds below the main speed and two above it, boosting of voltage-rise on the generators to give a linear law of acceleration and retardation, speed synchronization of the two motors by acting on the generator voltages, and equalizing their load currents by acting on the motor fields.

On continuous mills, supply is on the unit system, each motor having its own rectifier, and changes in motor speed due to load fluctuations are compensated by field changes. The automatic control system is provided with negative feedback according to speed.

Ingot conveying. The ingot conveyor drive motors use a Ward Leonard system with amplidynes and 'lift circuit'. During operation the operator selects a group of soaking pits and the ingot carrier is directed to the roll train, is automatically retarded and accurately positioned, the cradle is tipped, and the ingot passes on. The ingot delivery equipment includes a weighing roll train and operates automatically by means of photo-electric relays associated with the roll trains.

Reversing rolling. The direction of rotation of the roll trains and of the mill rollers is controlled by photo-relays according to the position of the billet. The rate of take-up, the maximum speed of rolling and the retardation are controlled by photo-relays observing the length of the billet. Acceleration after billet take-up is related to detection of roll sliding as shown by characteristic impulses in the mill motor current with subsequent controlled speed-reduction until sliding stops.

Continuous rolling. This mill consists of a delivery roll train with turntable: a four-stand black group; an intermediate roll train; a six-stand clean group; flying shears and collecting mechanisms. Alternatively, after the intermediate roll train the material may go to a by-pass line with heavier flying shears and then back to the same collecting mechanisms.

All the flying-shear mechanisms are fully automatic and are operated by photo-relays observing the passing metal. The electric drive of the shears is synchronized with that of the last stand of the rolling mill by synchros and a tachogenerator. Angular synchronization by synchros is only used for cutting the front end of the metal and thereafter the traverse of the shears is synchronized for measured lengths by a tachometer circuit according either to the speed of the last stand or to that of the special follower rolls. The latter are installed between the last stand and the shears so as to allow, if necessary, for minor variations in the advance of the metal or of the speed of the rolls.

Automatic screw-down for blooming-slabbing mills

Fouassin described the work carried out since 1952 on a blooming-slabbing mill at the Ougrée-Marihaye Steel Works in Belgium. The system uses synchro detection of the screw-down setting, with a tapped transformer and relay combination to give analogue-to-digital conversion. The selection of any three relays out of a total of thirty-eight gives 1650 combinations of screw-down target position, and accuracy is better than a tenth of a millimetre measured at the rolls. The amplified error signal is fed to a Westinghouse Rototrol controlling the d.c. screw-down motors through a motor-generator set.

The programming problem is to feed the required three-relay combination, and punched cards were originally tried for this. They appear to have failed for a number of reasons, but mainly because of diversification of programs and failure of the ingots to reach the mill in the correct predetermined order and state owing to temperature and metallurgical variations. Apparently states of confusion were created with the operator shuffling punched cards, with disastrous consequences in mill-time lost. They therefore abandoned the attempt to pre-program the mill, which is only considered as a practical procedure for long standard runs, and turned their attention to local automatic control, deciding to use uniselectors for memorizing a pass program. A six-bank 25-step uniselector can be used to store two 25-pass programs, since three of the contacts on a uniselector bank can uniquely define the three relays corresponding to one out of 1650 positions of the screw-down system as described above. To work the mill, the operator selects by switch the particular half-uniselector required and presses the start button. He then keeps on pressing the button after each pass, and the uniselector motors round to the next bank and resets the target screw-down position. This system has been found to be extremely reliable. Developments are now in hand to provide the operator with a keyboard into which he may punch information on the incoming ingot and the required final size, and this will automatically select the correct program.

Cement industry

Schink (Germany) described improved methods of control related to the crushing, grinding and kilning processes involved in the preparation of Portland cement by the 'dry' process. The efficiency of the crushing of lime-stone, the primary process in cement manufacture, has been increased by 25% by control methods designed to avoid excessive overloading of the crusher motor and yet to avoid also the fluctuations caused by simple overload on-off control. The method is to detect current in the motor circuit as a measure of load, and this is linked to cause an inverse linear relationship to the speed of the feed conveyor. The system uses a reset time of two minutes to smooth out minor fluctuations and the proportional range is 30% of normal load. Beyond the permissible range of overload, photo-electric detectors on the current meter stop the input conveyor entirely until the current drops to a reasonable value.

Schink went on to describe the control used in all the principal processes of cement making, but these do not appear to differ substantially from current British practice.[1] Some work has been carried out on the control of fine grinding by noise measurement, the total range being 100–110 phons. It is said that limits of better than 0·2 phon, which is an inaudible difference, must be maintained for good control, but the system is showing promising results.

Outstanding British contribution

Relatively speaking the contribution of practical papers by Britain to the Ifac Congress was outstanding. Below is a summary of some main practical developments described in the British papers. I have omitted two of them—Hemingway and Dressler's account of an automatic machine for building bicycle wheels, and MacDonald and Withers' description of automatic control in the British Sugar Corporation—only because abstracts of these papers appeared in the July issue of CONTROL (pp. 86–87), and because there is extreme pressure on space this month.

Ship stabilization

Following a brief outline of the various possible methods of ship stabilization against rolling, Bell stated that the only practicable and economic method at the present time is to use fins for anti-roll torque.[2] Bell was the originator of the compensating system developed by Muirhead's, and which is now installed on a considerable number of liners, including some of the largest ships afloat.

The worst condition of ship rolling occurs when the frequency of wave swells coincides with the natural rolling frequency of the vessel considered as a periodic pendulum, and passive damping techniques are quite inadequate to deal with this critical state. Under these conditions rolling will build up to excessive displacements corresponding to the point where the damping caused by rolling displacement is in equilibrium with the disturbing forces. It is found in practice that vessels may have a resonant q of about six, which will cause natural resonant rolling of about $\pm 18°$ in a moderate swell.

Development work towards a solution was undertaken in collaboration with analogue computer facilities at the National Physical Laboratory, and 300 tests were made with a hundredfold step-up over natural roll frequencies. A further experimental development was the setting up of a rolling table as an analogue of ship motion to test the speed of sensing devices. The result of this work has been the production of a range of anti-roll controllers covering ship sizes of from 30 to 80,000 tons displacement. For small ships the basis of control is a gyroscopic roll-velocity detector which operates hydraulic pilot valves to actuate the anti-roll fins in proportional counter action.

In large vessels, two gyroscopic devices are used for measurement, the first giving information for feedback control relative to list, and the second giving information relative to roll velocity and acceleration. The equipment requires careful adjustment to the natural rolling period of the ship, and control related to acceleration conditions appears to be both vital and critical.

Readers who have experienced the remarkable corrective action of these systems on transatlantic liners against rolling may wonder if the solution to pitching has also been found, but this is a matter still under study.

Automation in steel

Bramley, Carlisle and Sims described instrumental developments on steel-strip-width and velocity measurement, automatic gauge control and the automatic programming of rolling mills.

The hot-strip width-measuring system consist of two identical photo-electric systems receiving the infra-red radiation from the edges of the strip and controlling servo-operated shutters. The latter move to keep the radiation in the cells constant, and the motion is a measure of strip-edge variation. Facilities are also provided to compensate for variation in temperature of the radiation, and the compensated output of the two edge systems are combined to give total strip-width independently of the lateral position of the whole strip.

A development also described was for the non-contact measurement of steel-strip velocity. This uses two focused light spots with two photocell pick-ups, the two systems being displaced in the direction of strip travel. The cells pick up reflected light noise of identical nature but displaced in time. Means are provided (by means of a correlation coefficient generator) to assess the lag in signal wave-form recurrence, and this measures strip velocity.

Experiments indicate that a velocity accuracy of ¼% can be achieved in the speed range 100–1000 ft/min using light spots 0·05 in. in travel-width spaced 14 in. apart.

A multi-progam device was described for programming successive passes in rolling mills using uniselectors to define a given screw-down program. Following selection of the program, the operator presses the sequencing button after each pass. This system, for which some novelty is claimed, appears to be very similar to the one described earlier in this article and by M. Fouassin of Belgium.*

Automatic control on the British grid

Casson, Moran and Taylor described the systems developed for the automatic control of power-frequency on the British grid system. The basis of the system is that an automatic controller determines the system generation error from the measured values of frequency and power transfer, and transmits a signal to all stations so that the total generation error is reduced to zero. The controller has been designed for location at the national control centre and is based on mixed proportional, integral and derivative actions. Development of the system was carried out on an electrical simulator and showed the desirability of incorporating a term proportional to the second integral with respect to time of the deviation.

Two types of individual machine controller have been developed, in each of which the electrical output of the generating set is compared with the required target notified from the central control point, and any correction necessary is made by adjusting the governor gear through the speeder-motor of the set.

The communications for the system are over rented Post Office lines and the outgoing signals from the central control are visually displayed at the local centres with a return signal acknowledging receipt.

Developments are in hand to extend the scheme by locating an automatic controller in each grid control centre to give simultaneous control of all inter-area power flows and frequencies, but leaving the economic aspects of load dispatching to be dealt with manually, and consideration is being given to automatic control of this factor, although it is debatable whether the savings to be achieved are worth while.

Next month, Dr. H. H. Rosenbrock, Professor J. C. West and Dr. J. H. Westcott will report what they saw during the technical visits.

[1] See *Automatic control in the cement industry* by G. Field & S. R. Barker, CONTROL, March 1960, p. 91—EDITOR

[2] Cf. *Servos bring stability at sea* by John Bell, CONTROL, December 1958, p. 264—EDITOR

* Cf. *Uniselectors enter automatic program control* by H. Law, CONTROL, Sep. 1959, p. 96, and Oct. 1959, p. 93—EDITOR

Control equipment is more than a handy attachment, judging by the number of specially designed machine tools displayed at last month's international show

More control on machine tools

by **E. J. C. FOWELL**
R.A.E. Farnborough

THE INTERNATIONAL MACHINE TOOL EXHIBITION HELD recently at Olympia, London, under the auspices of the Machine Tool Trades Association, was the first to take place in the United Kingdom since 1956. At the present rate of technological progress, four years represents an appreciable interval of time, during which the machine tool industry, with the co-operation of firms specializing in industrial control, and with the help of government laboratories, has been adapting new techniques such as numerical position control to its equipment.

Thus at the 1956 exhibition, numerical control equipment for machine tools was something of a curiosity and it was received with mixed feelings. Men whose livelihood was governed by cams, end stops, trip-dogs, and similar well-tried mechanical devices, gazed askance at the frail boards with their assemblies of resistors, wire, and delicate glass bulbs which were supposed to cohabit with their sturdy machines. But in the succeeding years the distrust has lessened; the equipment has been improved, tried, and simplified; in many instances the much maligned thermionic valve has been replaced by the perhaps indefatigable transistor. Now, four years later, numerical control equipment is mentioned *en passant* in the exhibition catalogue as if it were no more than some handy attachment to be fitted to a machine as an optional extra. That this is hardly true can be gauged by the number of controlled machines on show that have been either specially designed from scratch, or severely re-designed to meet the stringent conditions which obtain when a machine tool becomes part of a servo-control system.

Archdale's Autonomic drill

For example, James Archdale and Co. showed their new Autonomic co-ordinate drilling machine which was specially designed for operation with a position control

Fig. 1 Archdale's Autonomic co-ordinate drilling machine employs moiré-fringe position-measuring techniques

system developed jointly by the research department of the Staveley Coal and Iron Co. and the National Physical Laboratory. The machine itself (Fig. 1) has a 6-ft-by-6-ft table capacity, the table floating on externally pressurized oil bearings. The employment of this tech-

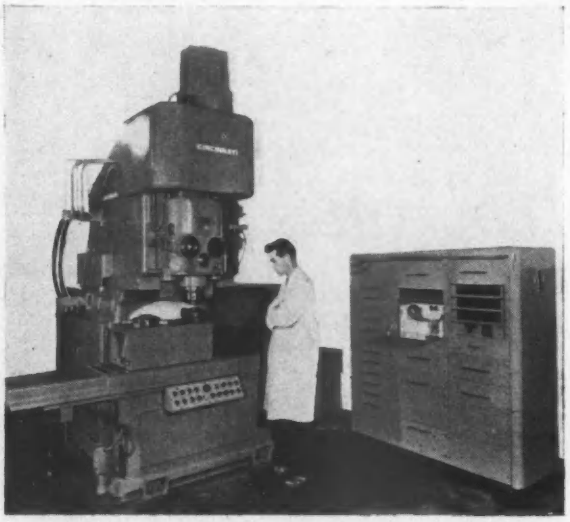


Fig. 2 This Cincinnati Hydrotel machine for contour-controlled milling is fitted with the E.M.I. Emicon system

nique, whilst virtually eliminating slideway wear, also allows the use of a small motor for table positioning. With a maximum all-up table weight of over seven tons, the fast table-traverse is carried out at 120 in./min by a 1-h.p. motor.

The tool turret of the machine can accommodate up to fifteen tools and a gauging plug for setting-up purposes. The tools are recognized by coded grooves around the holder, so that it is not necessary for them to be returned to their original positions in the turret. Appropriate tool-feed cycles are provided for drilling (up to 1¾-in. diameter in mild steel), tapping, or spot-facing, and the conditions are pre-selected at the control console for each tool.

In operation, the hydraulically-balanced cross-rail is clamped at a convenient height and tool feed is obtained by a hydraulically-operated quill-feed in steps of 0·01 in. Provision is made for spot-facing to be carried out at intermediate depths.

The position measuring equipment uses 100 line/in. optical transmission gratings arranged to produce moiré fringe patterns. Photo-cell signals derived from the patterns, are modulated by phased carrier signals and combined to give a further a.c. signal whose phase displacement is a measure of the fractional displacement within one grating pitch to an accuracy of 5% or better. Thus, with the grating pitch used, the system is capable of measuring static position to an accuracy of 0·0005 in. or better. A paper describing this system of measurement is to be published shortly in the *Proceedings of the I.E.E.*

Controlled milling

The use of long hydraulic rams for table positioning in machine tools is well established. Such long rams, however, are generally unsuitable for use as elements in a closed position-control loop unless they are of substantial cross-section, and even then it may be necessary to use sophisticated methods of control. The trouble arises from the low bulk-modulus of the hydraulic fluid, this imparting a spring-like characteristic to the drive. The spring can resonate with the table mass at frequencies low enough to render the drive useless for inclusions in any high-performance servo-loop.

In view of this, it is not surprising to find that the version of the Cincinnati 16-in.-by-30-in. Hydrotel milling machine (Fig. 2) especially developed for contour-controlled milling, has its longer motions, formerly ram-powered, is now driven by alternative means. The 30-in. longitudinal travel on this machine is now obtained by means of a sturdy 4½-in.-diameter leadscrew with re-circulating ball nut, which is directly coupled to a low-speed hydraulic motor of special design. The machine was shown with the E.M.I. Emicon control system(*1*), the position pick-off on the long traverse being obtained from the shaft of the hydraulic motor. The lack of manual controls on this machine gives it a clean appearance and is perhaps indicative of the greater faith now being shown in numerical control equipment.

A.E.I.-Newall jig borer

The A.E.I. system of continuous position control for contouring machines has recently been described in this journal (*2*). One of the outstanding points of this system is that although the computational facilities are entirely digital, it nevertheless allows offsets for cutter-diameter variation and for intermediate machining passes to be carried out at the machine tool console

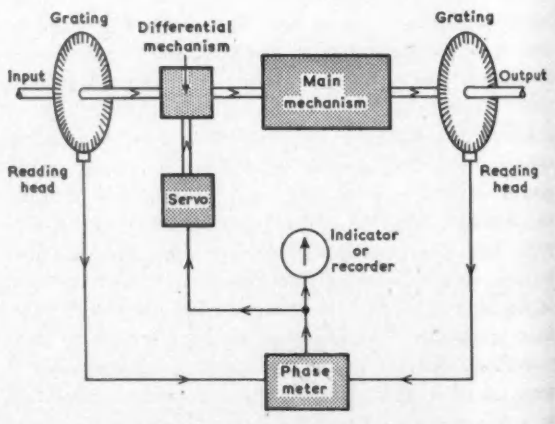


Fig. 3 Transmission errors between the spindle and work-table motions of a David Brown gear-hobber are reduced by means of this N.E.L.-designed servo-system

itself, without the necessity for referring back to the main computer, or for producing a separate length of tape for every pass. This is done by interleaving the co-ordinate positional information on the magnetic tape from the main computer, or 'director', with direction cosine information from which the cutter offsets are computed in a simple fashion, using the effective cutter diameter value as set up on the machine console. The main functions in the console unit are performed by miniature relays, time-sharing between the axes ensuring that the minimum of equipment is required.

A.E.I. operate a customers' magnetic-tape service centre at Leicester.

The A.E.I. system was demonstrated at the exhibition on the Newall 1520 CC jig borer. This particular machine is also available with Airmec's Spacematic control equipment for co-ordinate positioning.

Reducing transmission errors

David Brown Industries displayed two gear-hobbing machines with servo-reduced transmission errors between the hob spindle and the work-table motion. The technique, which was developed by the National Engineering Laboratory, involves the use of angular measurements taken at the spindle and the table.

The diagram, Fig. 3, shows how any discrepancy in the angular information is used to insert relative motion between the two parts of the machine. The system as originally developed, and using moiré-fringe techniques, was shown fitted to a 30-in. capacity production gear-hobber. A turbine-gear hobber of 140-in. capacity was also on display (Fig. 4). This machine uses E.M.I. Emisyn control gear based on the rotary Inductosyn element.

E.M.I. angular-positioning control also appeared on the S.I.P. (Genévoise) Ltd. Rotoptic 31-in. rotary table, and on a 30-in. diameter table by Optical Machine Tools. Both units demonstrated angular repeatability to within one second of arc. The input information is supplied by dial setting or standard teleprinter-tape input in both instances. A further rotary table, produced by The Gear Grinding Co., in association with Sperry Gyroscope, is claimed to be capable of repeating angles to a quarter of a second of arc.

Large plano-miller

The size of an exhibitor's stand appeared to be more of a limitation than mere transportability as far as the larger machines were concerned. However, Kendall and Gent showed a plano-milling machine of table capacity 20 ft by 6 ft, though the bed of the machine had sections missing in order to get it on the stand. The plano-miller is provided with electronic speed control of both horizontal co-ordinate movements. The control system, developed by A.E.I., allows the operator to select a desired cutter-feed rate, and steer the cutter around a marked-out profile on the workpiece, the control system ensuring that the rate of feed is maintained at any angle of traverse. This form of control is also available on a smaller vertical milling machine in combination with facilities for copy milling.

Fig. 4 This 140-in. turbine-gear hobber by David Brown has E.M.I. Emisyn control gear based on the rotary Inductosyn

Steering control has the appeal that, whilst the operator is being aided in his task by the control system, he is still able to use his judgement and experience. This is especially valuable when handling roughly-formed blanks which may vary greatly in character from piece to piece.

Numerical plus tracer control

An interesting demonstration of a combination of numerical contouring and tracer control was given on a Hayes Tapemaster milling machine fitted with Ferranti Mk IV numerical control. The demonstration showed the production of a curved name-plate from a tape programmed to produce a flat one. An unmarked curved plate under the tracer head represented the actual surface shape required on the name-plate. The two horizontal motions were controlled by the input tape alone, but the vertical motion was provided by adding the height of the tracer head to the tape information. Provided that the surface curvature is not too severe, it is thus possible to produce three-dimensional surface-figuring from a relatively simple two-dimensional control-tape input.

Three-dimensional controlled miller

At last year's Paris International Machine Tool Exhibition, High Precision Equipment showed a two-dimensional contouring machine fitted with Ferranti numerical control. At the present exhibition, the machine has been taken a stage further to give the Contourmatic three-dimensional machine which has a controlled spindle-feed (Fig. 5).

The machine-slides run on Dexter re-circulating ball type bearings. The table is stationary and the three co-

ordinate movements are all carried out by the head, the cross traverse of 12 in. being by hydraulic ram, and the 48-in. longitudinal traverse by lead screw and re-circulating ball nut from a hydraulic-motor-driven gear-box. The hydraulic power supply is contained in the box-like bed structure. A positional accuracy of 0·0005 in. is claimed for the machine under continuous contouring conditions.

Co-ordinate tables

The Atlantic co-ordinate table is now available with four possible position-control systems providing accuracies varying from 0·001 in. down to 0·0002 in. Two such tables were exhibited. One was fitted to an Asquith radial drilling machine in conjunction with the Ekco static position-control system. The second table was demonstrated on its own, with Ferranti static positioning equipment. The input to this equipment is by dial setting, or five-hole teleprinter tape using a one-hole-in-ten code. This coding allows a simple multi-element reading head to read two co-ordinate settings plus auxiliary information at one tape setting, thereby obviating the need for buffer storage, and simplifying the equipment. The grating elements for sensing position are supplied in linear form along the edges of the table or in circular form at the driving lead-screws, depending on the positional accuracy required.

Spark machining

The machining of hard metals into intricate shapes by a process of electric spark erosion while immersed in a dielectric (such as paraffin) is becoming an increasingly attractive proposition, especially for die-sinking. There was a fair selection of spark-erosion machines at the exhibition. S.I.P. showed a Genévoise optical jig-borer fitted with a spark-erosion head by the Swiss firm A.G.I.E. The electrode-feed rate, when used for

Fig. 5 High Precision Equipment's three-dimensional Contourmatic contouring machine with Ferranti control

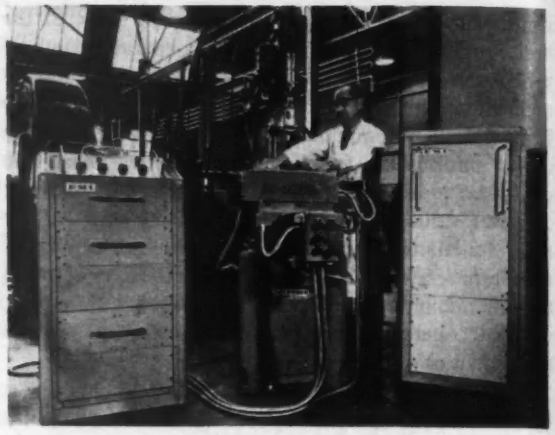


Fig. 6 This E.M.I.-Grimston tape-controlled drilling machine, which has been designed for the small batch producer, has an automatically-programmed seven-position turret head. Costing just over £2000, its automatic cycle includes, drilling, reaming and tapping of 130 holes of two sizes in steel plate

die-sinking, is governed by a servo-control loop which adjusts the spark gap from the information which it derives from the desired spark-current setting and the actual mean spark current. Wickman demonstrated their range of Erodomatic machines with servo-controlled feed (as described above), and with servo-controlled spindle rotation under free vertical movement to allow the tapping of threaded holes or the production of helical forms in the workpiece.

Rotor balancing

Away from the process of machining altogether, E.M.I. had a model of their new C.S.6 dynamic balancing machine which can accept rotors weighing between 25 lb and 250 lb in weight. The amount of unbalance, referred to two conveniently chosen planes, is shown on a meter panel, the angular position of the unbalance being indicated by a stroboscopic lamp. The machine is able to detect out-of-balance displacements of the order of 8 μ in. by the use of novel forms of pick-up transducer and cradle suspension.

Conclusion

There were many other items on display of interest to the control engineer but it is hoped that the reviewer will be excused for having made his own selection of reportable topics.

Taken altogether, this was a very interesting exhibition—one which showed that the machine tool industry is not quite the stick-in-the-mud reactionary body that it sometimes pretends to be.

Acknowledgement

This review is published by permission of the Chief Scientist, Ministry of Aviation. The views expressed are not necessarily those of the author's Department.

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PART 1

Efficient and robust, this new semiconductor device will not only replace the thyratron in many cases —it will open up fresh fields of application

The silicon-controlled rectifier

by **A. J. SADLER AND P. A. TURNER**

A.E.I. (Rugby) Limited

SILICON AND GERMANIUM RECTIFIERS HAVE MADE IT feasible to rectify more efficiently than before, but their use has been limited because control of output has not been possible. This disadvantage has been overcome with the new device, the silicon-controlled rectifier, which has electrical properties very similar to those of a thyratron whilst retaining the advantages of solid-state devices.

In the reverse direction, the controlled rectifier has a characteristic similar to that of a conventional silicon rectifier. In the other direction the device has two regions of stable operation, one of high impedance, of the order of megohms, which can be changed to a low impedance of the order of fractions of an ohm. The transition is extremely rapid, and can be effected either by exceeding a voltage characteristic of the device, called the 'break-over voltage', or by injecting a small current into a third electrode.

As with other semiconductor devices, very compact units can be made, capable of handling large powers extremely efficiently, the low-impedance condition being that of a single-junction rectifier. In this article we shall discuss their operation, method of preparation and electrical characteristics, and we shall mention some typical applications.

Mode of operation

A silicon *pn* junction has a characteristic as shown in Fig. 1. When the *p* region is positive with respect to the *n*, the junction passes current easily and is said to be 'forward biased'. The potential drop in the forward direction is of the order of a volt. In the reverse direction, i.e. *p* region negative, the junction passes only a small current which is not a function of the voltage across the device. This is referred to as a 'saturation current'.

When the reverse voltage across the junction reaches a certain value, dependent on the impurities in the two regions, current-carrying holes and electrons are accelerated by the high fields and there is ionization by collision. An increased number of holes and electrons then becomes available for conduction, leading to higher currents. The multiplication factor increases with increasing voltage, and at a value known as the break-down voltage of the junction, becomes almost infinite.

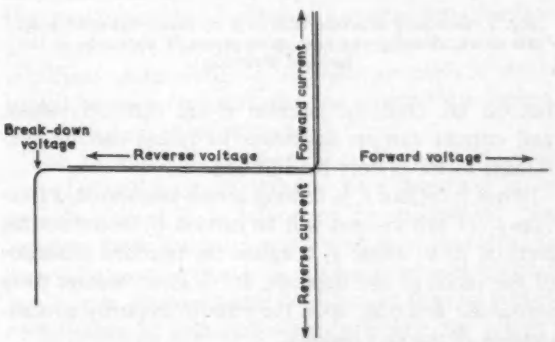


Fig. 1 Electrical characteristic of a pn junction. This diagram shows the rapid increase of reverse current at the break-down voltage

The basic part of a controlled rectifier is a silicon slice containing three *pn* junctions. This is shown diagrammatically in Fig. 2. The positions of the junctions and the impurity content of the four regions can be designed to give the electrical characteristic shown in Fig. 3. With the p_1 region positive with respect to the n_2 region (i.e. in the forward direction) the device passes small currents until the switching voltage is reached, and then the impedance falls to a very low value and

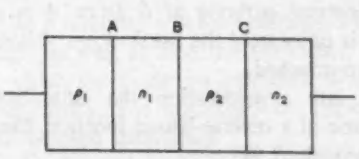


Fig. 2 Block diagram of a pnpn structure

high currents are passed with a low voltage drop. This switching voltage, the ' break-over voltage ', is not necessarily the break-down voltage of any of the component *pn* junctions.

With reversed polarity, the characteristic is similar to that of a single reverse-biased *pn*-junction rectifier.

In the forward direction, at voltages below the break-over voltage, junctions A (p_1 n_1) and C (p_2 n_2) are forward-biased, and the main voltage drop will occur at B (n_1 p_2). The current through the device will be limited to the order of the saturation current of junction B. Therefore the electrical fields in the bulk of the silicon

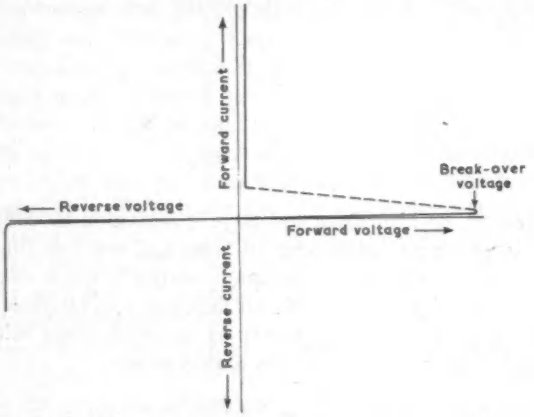


Fig. 3 Switching characteristic of a correctly designed pnpn structure, showing the two stable states of operation in the forward direction

beyond the limits of junction B are extremely small, and current carriers (electrons or holes) can be considered to travel only by diffusion.

When a current I_1 is flowing across junction A, a fraction γ_1 of this current will be carried by holes flowing from p_1 to n_1 where γ_1 is called the injection efficiency of the junction and depends, for a given voltage drop across the junction, upon the relative impurity concentrations of the two regions.

These holes will diffuse towards junction B and a fraction β_1 will arrive at B, the remainder recombining with electrons. The transport efficiency of the region, β_1, is dependent both on the width of the region and the ' diffusion length ' of the holes in the n material. The diffusion length is a measure of the average distance a minority carrier (i.e. holes in n, or electrons in p), will diffuse before it recombines. Thus for low voltages the hole current arriving at B from A is $\beta_1 \gamma_1 I_1$.

Near the break-down voltage, the holes arriving at the high-field region associated with the reverse-biased junction will be multiplied by a factor M, which is a function of the voltage across the junction. Therefore the hole current arriving at B from A is $M \beta_1 \gamma_1 I_1$, where M is unity until the break-down voltage of junction B is approached.

Taking into consideration the saturation current characteristic of a reverse-biased junction, the total hole current through B is

$$M \beta_1 \gamma_1 I_1 + M I_{hs} \quad \ldots (1)$$

where I_{hs} is the fraction of the saturation current that consists of holes.

Similarly, the electron current passing through B is affected by junction C, and equals

$$M \beta_2 \gamma_2 I_2 + M I_{es} \quad \ldots (2)$$

where β_2 is the transport efficiency of region p_2; γ_2 the injection efficiency of junction C; I_2, the total current flowing though the junction C; and I_{es} is part of the saturation current of junction B which consists of electrons. Therefore, the total current flowing through B is:

$$M \beta_1 \gamma_1 I_1 + M \beta_2 \gamma_2 I_2 + M(I_{es} + I_{hs}) \quad \ldots (3)$$

Now since the total current I through the device is continuous

$$I = I_1 = I_2 \quad \ldots (4)$$

Combining equations 3 and 4, we have:

$$I = \frac{M(I_{es} + I_{hs})}{1 - M(\gamma_1 \beta_1 + \gamma_2 \beta_2)}$$

or

$$I = \frac{M I_s}{1 - M(\gamma_1 \beta_1 + \gamma_2 \beta_2)} \quad \ldots (5)$$

where I_s is the total saturation current of junction B.

If under certain conditions

$$M(\gamma_1 \beta_1 + \gamma_2 \beta_2) = 1 \quad \ldots (6)$$

the denominator in equation 5 is zero, and the current is limited only by the resistance of the external circuit. Under these conditions junction B must be injecting holes into n_1, and electrons into p_2. This implies that junction B is effectively in the forward direction and has switched to a state of easy current flow. The voltage at which this occurs is called the break-over voltage V_{BO}.

By considering the conditions under which $M(\gamma_1 \beta_1 + \gamma_2 \beta_2) = 1$ the types of electrical characteristics obtainable from a four-region *pnpn* device can be predicted.

In a device in which $M(\beta_1 \gamma_1 + \beta_2 \gamma_2) = 1$, mainly from a large increase in M as the break-down voltage is approached, a forward characteristic of the type shown in Fig. 4a results, the break-over voltage being substantially the break-down voltage of junction B. This is called ' multiplicative ' switching.

In a practical device, small leakage-paths across the surfaces of junction B give rise to small currents that pass through regions n_1 and p_2 and that will increase slowly with increasing applied voltage. As the current increases, the diffusion length of the current carriers varies in such a way as to make β_1 and β_2 increase. Thus $M(\gamma_1 \beta_1 + \gamma_2 \beta_2)$ increases, and devices can be made which switch well below the break-down voltage of the centre junction. Increased junction temperatures also lead to higher leakage-currents and therefore to lower break-down voltages. The phenomenon is called ' current transport ' switching (Fig. 4b).

If the device is made with the thicknesses of the regions p_2 and n_1 too small, so that β_1 and β_2 are large even at extremely small currents, expression 6 holds immediately the device is biased in the forward direction. Such a device may be said to be permanently

switched, and shows the general forward characteristic of a simple *pn* junction (Fig. 4c).

β_1 or β_2 can be increased by changing the current density through either junction *A* or *C* by means of a third electrode on region n_1 or p_2, and biasing the appropriate junction in the forward direction with an external supply. With careful design, devices can be made with V_{BO} reduced to zero for quite small currents through the third electrode. It is by this means that the device can be used as a controlled rectifier.

A light source can be used to generate the extra carriers needed to trigger these devices, and their application as a photo-relay is possible.

Manufacturing processes

A *pnpn* structure can be fabricated in a number of different ways. The controlled rectifiers under consideration in this article combine both diffusion and alloying processes.

The cross section in Fig. 5 shows a *pnp* wafer of silicon soldered to a metallic base. The *pnp* structure is formed by diffusion of a *p* impurity into an *n* silicon wafer. The outer *n*-layer shown in the diagram is formed by alloying an *n* impurity into the silicon. The trigger connexion is an alloyed contact which makes ohmic contact with the *p*-layer.

By the controlled diffusion of a suitable *p* impurity, such as gallium, aluminium or boron, into an *n* slice of silicon, a *pnp* structure is created. The process involves the sealing of thin silicon slices, with faces parallel within fractions of a thousandth of an inch, together with the impurity element, in a quartz tube filled with

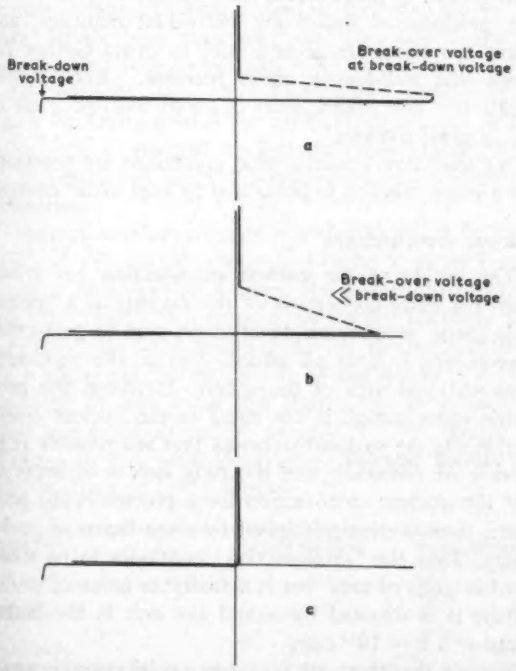


Fig. 4 Types of switching with pnpn device: **a**. Multiplicative switch—ideal characteristic for a controlled rectifier; **b** Current transport switch; **c** permanent switch

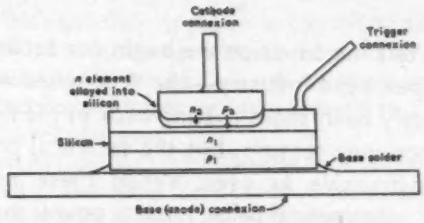


Fig. 5 Construction of a silicon-controlled rectifier: the slice of silicon contains two pn junctions formed by diffusion and one formed by alloying. Spacing of these junctions is critically important in obtaining the required electrical characteristics

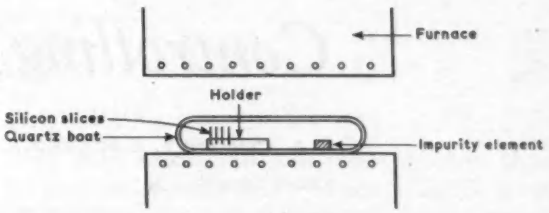


Fig. 6 Diffusion process: the slices are held at high temperature for several days in order to allow the p impurity to diffuse over a sufficient distance into them

an inert gas. The assembly is then heated to a temperature of between 1200°–1300°C and held there for several days until the correct penetration of the impurity has been achieved. The diffusion apparatus is shown in Fig. 6. As the rate of diffusion is particularly sensitive to temperature, accurate temperature-control is very important. After diffusion, the tube assembly is slowly cooled to room temperature, the quartz tube broken, and the silicon slices removed.

The *pn* junctions are formed at the point at which the *p* impurities exactly balance the *n* impurities in the original silicon. It is important for subsequent processes to know the exact position of these junctions. To determine these, a silicon slice is sectioned and the position of the junctions found by means of thermal probes, or by using an acid etch which will stain the *p* layers

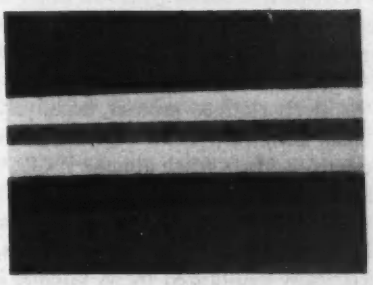
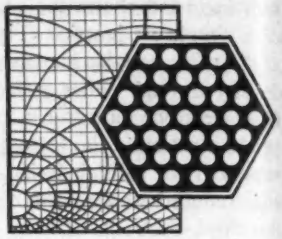


Fig. 7 Section through diffused slice, stained to show p and n regions

(Fig. 7). The *p* impurity will have diffused into the edge of the slices as well as into the two faces. This edge diffusion, which shorts the *pn* junctions, is removed by grinding or cutting. The resulting slice will have a high impedance in both directions.

To be continued

With this introduction we begin our second series of articles on control in a spearhead industry—the first series was on guided missiles.* There has lately been some cutting back in the nuclear power program, mainly for economic reasons, but the technical problems are still as fascinating and instructive as ever. When these problems can be solved at a commercial price, nuclear power must come into its own



Controlling nuclear power

by **A. CONWAY, B.SC.(ENG.), A.C.G.I., A.M.I.MECH.E.**
Editor, Control

CONTEMPORARY NUCLEAR REACTORS ARE USED TO PRODUCE electric power by a rather indirect route: the controlled nuclear reaction provides heat to raise steam for fairly conventional electric generating plant. While there are prospects of producing electricity by a less circuitous path in the future, we shall in this series of articles limit ourselves to the methods of the present time. The nuclear power station, as we shall look at it, is one in which a nuclear boiler replaces a fossil-fuelled boiler. The biggest single difference between these two kinds of boiler is in the source of heat, not in the way the steam is raised. In the nuclear reactor the heat arises from physical changes, while in the fossil-fired furnace the exothermic changes are chemical.

A brief recapitulation of some of the elementary physics is perhaps not out of place. In order to acquire a satisfactory picture of what goes on in a nuclear reactor we need take only a very simple model of the atom. We regard it as being built of three fundamental particles: positively charged **protons,** negatively charged **electrons,** and uncharged **neutrons.** Protons and neutrons are relatively heavy (each about $1{\cdot}7\times10^{-24}$g), while electrons are relatively light (about 10^{-27}g). Protons and neutrons are bound together (by forces not yet understood) in a massive, positively charged **nucleus,** and the atom is electrically neutralized by its satellite electrons. Nuclei are 2×10^{-12} to 2×10^{-13} cm across, the electron measures about 4×10^{-13} cm, and an atom spans something in the order of 10^{-8} cm. Thus most of an atom is empty space.

Neutrons passing through matter are not deflected electrically by electrons or protons, but on encountering a nucleus they may either bounce off it or be captured. The nuclei of some heavy elements may split into two parts after capturing a neutron, and by analogy with the reproduction of living cells this process is named **fission.** For reasons which we shall not enlarge upon, fission is an explosive event, and the total kinetic energy of its products exceeds the previous total kinetic energy of the particles: in other words, the temperature rises or heat is evolved. Each fission in uranium^{235} (the superscript will be explained later) releases $3{\cdot}2 \times 10^{-11}$ Ws, and power is proportional to rate of fission. Among the products of fission are individual neutrons, and these can penetrate other nuclei to cause further fissions—the well-known **chain reaction.** Each fission yields two new nuclei, each of about half the mass of the original nucleus.

We shall now consider what conditions are necessary for a chain reaction to occur and be kept under control.

Nuclear cross-sections

The notion of the **nuclear cross-section** has arisen from the early conception of the nucleus as a sphere. This shape presents an equal target-area to projectiles approaching it from all angles—that is, the maximum cross-sectional area of the sphere. However, the geometric cross-section is not equal to the nuclear cross-section for the various processes that are possible (e.g. capture or rebound), and the next step is to suppose that the nuclear cross-section for a process is the geometric cross-section multiplied by some factor of probability. Thus the 'cross-section' continues to be measured in units of area, but is actually an index of probability. It is denoted by σ and the unit is the **barn;** 1 barn = 1 b = 10^{-24}cm^2.

Suppose that there are N_0 target nuclei per unit mass of a medium of density ρ, and that a uniform beam of neutrons falls normally on unit area. If the beam passes

*Ended and summarized in CONTROL for June, 1960, p. 106 ▯

through a thickness δx of the medium, the mass of material traversed is $\rho.\delta x$ and the number of nuclei in this mass is $N_0\rho.\delta x$. If I is the intensity of the incident beam, the intensity after traversing δx is $I + \delta I$, where $\delta I = -IN_0\rho\sigma\,\delta x$. In other words, the beam is attenuated by an amount depending on the intensity of the incident beam and the total target area presented. Clearly the intensity at x is $I = I_0\exp(-\sigma N_0\rho x) = I_0\exp(-\sigma N)$ where N is the number of nuclear targets in the path of the beam. The value of σ depends not only on the nature of the target but also on the velocity of the incident neutron. The product $\sigma N_0\rho$ is denoted by Σ. This is in fact the cross section per unit volume, and is of dimensions L^{-1}. It can be shown to be equal to the reciprocal of the **mean free path.** The quantity Σ is known as the **macroscopic cross-section** of the material.

Neutrons in uranium

The only naturally occurring fissile element is uranium. This contains predominantly two isotopes: **isotopes** are elements, of which the atoms contain the same number of protons per nucleus but a different number of neutrons. The principal isotopes of uranium are U^{238} and U^{235}: the superscript gives the total number of neutrons and protons in the nucleus, and is called the **mass number.** Natural uranium is radio-active, and fissions occur in it spontaneously; that is, for no known reason but apparently by chance, 10^{-2} nuclei will fissure in every gram of U^{238} per second, and 3×10^{-4} nuclei in every gram of U^{235}. On the average, about $2\frac{1}{2}$ neutrons emerge after each fission of a uranium nucleus. The neutrons so born may end by being captured in a nucleus without causing fission, or they may induce fission. Newly born neutrons have high kinetic energy, and are therefore called **fast.** After bouncing off a few other particles, they may lose energy sufficiently to reach equilibrium with the surrounding atoms: in this state—one of thermal equilibrium—they are described as **thermal** neutrons. The bouncing process is known as **scattering.**

Natural uranium consists of about 99·3% of U^{238} and 0·7% of U^{235}. Both isotopes are fissile to either fast or thermal neutrons, but whereas the fission cross-sections are 0·29 b and 1·36 b respectively for fast neutrons, they are zero and 582 b respectively for thermal neutrons. In working out the probability of **fast fission** in natural uranium we can, for a first approximation, reasonably take the metal to consist entirely of U^{238}, though we cannot do this when considering **thermal fission.** For fast neutrons in U^{238} we have:

PROCESS	CROSS SECTION b	PROBABILITY OF OCCURRENCE
Fission	0·29	$\frac{0·29}{4·36} = 0·068$
Capture	0·04	0·0093
Inelastic scattering	2·47	0·57
Elastic scattering	1·50	0·35
	4·36	

Thus the probability of fission is only 6·8%, while the probability of scattering is dominant at 92%. After a few collisions the neutron has lost too much energy to be called fast any longer, and it is apparent that a chain reaction will not arise.

Thermal neutrons (conventionally, those with 0·025 eV of energy) find quite different cross-sections in their encounters with uranium nuclei. These are:

PROCESS	U^{238}		U^{235}		Nat. U	
	CROSS SECTION b	PROB'Y	CROSS SECTION b	PROB'Y	CROSS SECTION b	PROB'Y
Fission	0	0	549	0·834	3·92	0·251
Capture	2·8	0·254	101	0·153	3·5	0·224
Scattering	8·2	0·745	8·2	0·013	8·2	0·525
	11·0		658·2		15·62	

We know already that each fission produces about 2·5 neutrons—actually 2·47 is a nearer figure—so we can see that, in a system where only fission, capture, and scattering are possible, the ratio

$$\frac{\text{number of neutrons produced}}{\text{number of neutrons absorbed}} = \frac{2·47 \times 3·92}{3·92 + 3·5} = 1·3$$

In other words, for every thermal neutron absorbed there are 1·3 neutrons born. Clearly the population will expand and the self-sustaining chain reaction must occur—given the thermal neutrons.

Moderators

To thermalize neutrons born of fission, it is necessary to retard them. Atoms of U^{238} are massive compared with neutrons, so neutrons bounce off them with very little loss of energy, and a large number of collisions would be needed to slow down the fast neutrons to thermal energy. The chances of unproductive capture *en route* would therefore be high. To get over this difficulty we have to intersperse suitable atoms between the uranium nuclei. Material of this kind, intended to thermalize neutrons, is said to **moderate** their energy. Moderators are the better

1. the lower is their absorption of neutrons, and
2. the more effective is their retardation of neutrons.

The energy lost in a collision between a neutron and a nucleus is higher when the nucleus is more nearly of the same mass as the neutron—most nuclei are, of course, much heavier, and none is lighter. The denser the material, the more nuclei there are in a given volume, so the better chance there is of a collision in a certain travel. Hydrogen is a fair moderator with regard to absorption and retardation, but it is not dense. Generally speaking, graphite is as good a moderator as any, and has the practical advantages of cheapness and availability.

Mixing fuel and moderator

The relative chances of scattering, absorption without fission (to form plutonium^{239}), and absorption with fission, are quoted above for the two extremes of fast

neutrons and thermal neutrons. For neutrons having intermediate energies, the relative chances fluctuate irregularly as the neutron energy is reduced, and it is found that if neutrons have access to natural uranium during the process of becoming thermal, the predominant effect is capture, so the chain reaction is not sustained. By arranging the fuel and moderator in suitable lumps, however, neutrons born in one uranium lump can be thermalized before reaching the next. A system of this kind is called **heterogeneous.** Commonly, rods of fuel are placed in holes in a graphite stack—that is how the early nuclear reactors came to be known as 'piles'. A system with fuel and moderator intimately mingled, known as a **homogeneous reactor,** can only be made to sustain a chain reaction if the chance of neutron capture without fission is reduced by raising the proportion of U^{235} compared with U^{238}—i.e. by the expensive process of isotope separation. Fuel with U^{235} added in this way is called **enriched.**

Multiplication in an infinite system

Suppose that there are N fast neutrons free in a system, each just born of fission; these constitute a **generation.** The ratio of the fast neutrons in the new generation to those that started the preceding generation (note that these have all been absorbed) is known as the **multiplication factor,** k.

If the life of a generation is constant in an infinitely large system—which it will be, given no changes in geometry or composition—then the population of neutrons will be constant provided that $k = 1$. Such a system is said to be in a **critical** state. If $k > 1$ the system is **supercritical** and the reaction **divergent,** and if $k < 1$ the system is **subcritical** and the reaction **convergent.** The population grows in a supercritical system and declines in a subcritical one.

Reactor kinetics

In a real reactor some of the neutrons escape at the boundaries, and this must be allowed for in calculating the multiplication. We define an **effective multiplication factor,** k_e, as

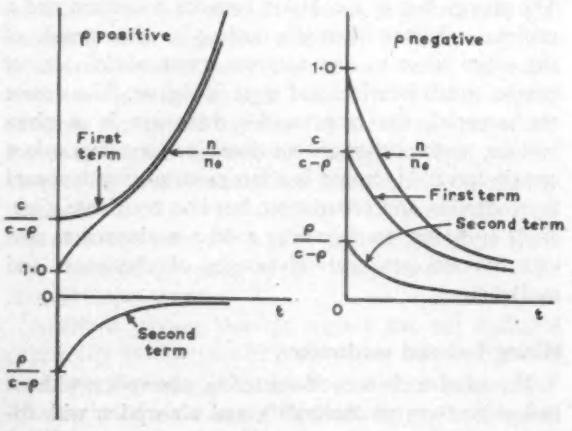


Fig. 1

$$k_e = \frac{\text{number of neutrons newly generated}}{\text{no. of previous gen. absorbed} - \text{no. escaping previous gen.}}$$

so that, if k is the multiplication factor for an infinitely extended version of the mixture of fuel and moderator, then

$$\frac{k}{k_e} = \frac{\text{neutrons newly generated}}{\text{no. of previous gen. absorbed}} \times \frac{\text{no. of prev. gen. absorbed and escaped}}{\text{neutrons newly generated}}$$

$$= 1 + L_e$$

where L_e is the ratio of escapes to absorptions, or the **fractional leakage.** For criticality we now have $k_e = 1$ instead of $k = 1$.

Suppose there to be n free thermal neutrons in a reactor at a given instant. Then

$$\frac{dn}{dt} = \text{rate of production} - \text{rate of absorption} - \text{rate of leakage}$$

The rate of absorption is the number of the population divided by the average individual life. If the latter is τ_0 in the infinite system then the rate of absorption is n/τ_0. By definition, the rate of production in the infinite system is kn/τ_0 and the rate of leakage is $L_e n/\tau_0$. Hence

$$\frac{dn}{dt} = k\frac{n}{\tau_0} - \frac{n}{\tau_0} - L_e\frac{n}{\tau_0} = k\frac{n}{\tau_0}\left(\frac{k_e - 1}{k_e}\right)$$

The bracketed expression, denoted by ρ, is known as the **reactivity.** In normal running, $k_e \simeq 1$ and $\rho \simeq k_e - 1$. Some writers prefer to work in terms of this quantity, $k_e - 1$, and they call it 'excess k'; it may be negative, of course.

If the reactivity is zero at $t = 0$ (i.e. the system starting from the steady state) and a step change is made in reactivity, the solution to the above equation is

$$n/n_0 = \exp(\rho k t/\tau_0)$$

where n_0 is the number of the population at $t = 0$.

If there is a radio-active source in the system, producing neutrons at a rate S (say), then the d.e. becomes

$$\frac{dn}{dt} = \rho k\frac{n}{\tau_0} + S$$

giving the solution

$$n = -\frac{S\tau_0}{\rho k} + \left(n_0 - \frac{S\tau_0}{\rho k}\right)\exp\left(\frac{\rho k}{\tau_0}t\right)$$

If $\rho < 0$ then, as $t \to \infty$ so $n \to S\tau_0/\rho k$. In other words, the population tends to reach a finite value in a subcritical reactor. If more uranium is loaded into the system the population rises rapidly and approaches exponentially to a new constant level. As the system is made bigger, the time taken to reach the steady state gets longer. When criticality is reached the reactor does not saturate at all. Extra uranium then makes the reactivity positive. With $\rho > 0$, $n \to \infty$ as $t \to \infty$. One might have $\tau_0 = 1{\cdot}5 \times 10^{-3}$ seconds and $\rho k = 1{\cdot}5 \times 10^{-4}$. So, if S is negligible, $n/n_0 = \exp t$, and the population (on this theory) would increase 150 times in five seconds. Clearly a population multiplying at this rate would

make exacting demands on the control system. But the products of fission may themselves be unstable nuclei, decaying radio-actively and emitting neutrons. The neutrons born at the instant of fission — called **prompt neutrons**—are therefore not the only ones produced. Some come later, and are named **delayed neutrons** for that reason.* These delayed neutrons save the situation, for they make the reaction controllable.

Let r be the number of nuclei which are capable of producing delayed neutrons, and which are in the reactor at a given instant, and let τ be the decay period for such nuclei. Let c be the fraction of neutron production that arises from delayed neutrons. Then, neglecting S,

$$\frac{dr}{dt} = \frac{ck}{\tau_0} n - \frac{r}{\tau}$$

$$\frac{dn}{dt} = \frac{nk}{\tau_0} (\rho - c) + \frac{r}{\tau}$$

For a step change of reactivity, if $\rho < c$, this gives

$$\frac{n}{n_0} = \frac{c}{c-\rho} \exp\left[\frac{\rho t}{(c-\rho)\tau}\right] - \frac{\rho}{c-\rho} \exp\left[\frac{\tau_0}{-k(c-\rho)t}\right]$$

Fig. 1 shows this result graphically. Comparing with the result obtained by neglecting delayed neutrons, we see that for a positive value of reactivity after an initial transient the neutron population still increases exponentially, but now with the time-constant $\tau(c-\rho)/\rho$. Typical values for a thermal reactor are, $\tau_0 = 10^{-3}$ sec, $\tau = 13$ sec, $c = 7{\cdot}5 \times 10^{-3}$.

Thus if ρ is small compared with c, the time-constant is about $0{\cdot}1/\rho$ sec; this may be compared with the time-constant obtained by neglecting delayed neutrons, given by $10^{-3}/\rho$ sec. For small values of reactivity, the time-constant has increased a hundredfold. It may be shown that as the reactivity approaches the value of c (the delayed-neutron fraction), the time-constant diminishes towards the value which would have obtained if no neutrons had been delayed; i.e. the reactor becomes **prompt-critical.** Actually the delayed neutrons arise from six types of emitter, each with its characteristic decay period τ_1, τ_2, . . . etc. If the fraction of neutrons absorbed in type-τ_1 emitters is c_1, etc., the average lifetime of the emitters is $\frac{1}{c}[c_1\tau_1 + c_2\tau_2 \ldots + c_6\tau_6]$. For many practical control calculations the emitters may be regarded as one group having the above average lifetime and an abundance given by $(c_1 + c_2 \ldots + c_6)$.

Running at power

If the reactivity is positive, the neutron density and hence the reactor power continue to increase as shown in Fig. 1, apparently without limit. In practice, as power increases, inherent changes in the reactor modify the reactivity and ultimately suppress the increase of power. The most important changes are due to temperature variation and to 'poisoning'.

Temperature variation changes reactivity by causing movements of the system components, and by affecting the temperature at which the neutrons are thermalized and the effective nuclear cross-sections of the components of the system. **Poisoning** is the accumulation of fission-product atoms, notably Xe^{135}, which have very high absorption cross-sections for neutrons and mop them up wastefully.

Thus the control of the power level of a practical system involves a sequence of events. A power change is initiated by altering reactivity (in a thermal reactor this is done by withdrawing control rods). Power begins to increase in the exponential manner shown in Fig. 1. In due course the temperatures increase; this feeds back a change to the reactivity and the rate of change of power is thereby modified. It happens that the most significant poison (xenon) is not formed appreciably from fission direct, but comes mainly from the radio-active decay of iodine, which in turn comes from the tellurium that constitutes about 3% of fission-product atoms. Owing to this indirect formation, there is a delay in the change of xenon-content following a power change, and for many control calculations the rapid temperature changes are more significant.

Using the heat

We began this introductory article by saying that the reactor in a nuclear power station is a source of heat for raising steam. This heat has to be transferred, possibly through intermediate stages, from the fuel to the water. Since water is itself an admirable moderator, the obvious solution is to use it as such and to boil it off for the steam turbines. This is not as simple as it sounds, and it raises some tricky control problems, but it is a method now being developed with some promise in the U.S.A. There are advantages in keeping the moderating water in the liquid phase (by holding it under pressure) and transferring the heat through a heat exchanger to water in a secondary circuit. The American nuclear submarines rely on this kind of system. Another approach is to use an organic liquid as moderator in the primary circuit.

This is not the place to go into the many different kinds and combinations of coolant and moderator. In the ensuing series of articles we shall mainly be concerned with reactors in which solid graphite moderates the energy of the fission neutrons, and in which the fuel consists of solid rods occupying channels cut in the graphite. The fuel is cooled by carbon dioxide gas which is blown through the channels and then through heat exchangers to raise the required steam.

Acknowledgement

Grateful thanks are due to Mr. J. H. Bowen of the U.K. Atomic Energy Authority, not only for reading the draft of this introduction and suggesting some improvements, but also for his advice on the construction of the subsequent series.

NEXT MONTH

The second article will be 'Automatic control of power reactor systems', by J. H. Bowen of the U.K. Atomic Energy Authority.

*The yield per fission consists of about 2·42 prompt and 0·08 delayed neutrons

Compared with meetings held in the early fifties, the latest conference of the British Computer Society was unexciting. The few interesting points are picked out in this short review

A lull in computers

by **R. A. BROOKER, B.SC. (LOND.), M.A. (CANTAB.)**
Manchester University

THE SECOND ANNUAL NATIONAL CONFERENCE OF THE British Computer Society was held at Harrogate from the 4th—7th July. There was little in the way of exciting new material presented, as used to be the case in computer conferences of the early 1950s. Instead, this meeting was largely devoted to the applications of computers in business data processing: there was no account of any technical developments, or logical design of computers or their components.

Common language

In the first session, entitled ' Progress towards a common language for computers ', Mr C. Strachey gave some account of the influence of large computer memories on programming techniques, and in particular referred to some recent developments in ' list structure ' programming. This refers to situations in which the relevant data consists of many hundreds of lists each of indefinite extent; so that one is faced with the alternative either of allocating in advance the maximum possible number of consecutive memory locations for each list, which would almost certainly exceed the memory capacity, or else of placing new items in the first available location in the order in which they turn up, and planting a connecting word to link items in the same list. These situations occur in the field of non-numerical and logical problems, such as game playing, pattern recognition, theorem proving and artificial intelligence.

The next speaker was Mr R. A. Brooker, who described some work being done at Manchester on a computer input routine for accepting any particular problem-oriented language. This is achieved by recognizing two distinct forms of input language. The primary one, which is a declarative language, describes the form and method of translating the secondary ' imperative ' language (or autocode). Each user may therefore write his own autocode. It is more likely, however, that a standard set of declaratives will arise, which define an autocode with a fairly large problem area. Specialist groups may then extend this to cover their particular problem areas.

The final speaker in this session was Mr R. M. Paine (I.C.T. Ltd.), who described the problems of autocoding for business application. The ideal form of a business autocode would be a form of English understood by accountants and o. & m. men, and which would also enable people who are not responsible for the detailed work to understand flow charts and processes. He described some of the difficulties which arise. For example, the fact that disciplined English still requires some concentration to understand its syntax and grammar, and that the meaning of the several accountancy terms such as ' post ', ' invoice ', ' balance ', varies from firm to firm; so nouns and verbs have to be defined and processes built up from small steps. Finally, he pointed out that although such a system would facilitate programming, there would still be a need for a lengthy system study before formulating the strategy of the program. In his view the idea of business autocodes has been over-sold and over-simplified, so that now too much is expected of it.

Market research

In the next session (' Computers in market research and statistical analysis ') Dr A. S. Douglas (C.E.I.R. (U.K.) Ltd.), described what amounted to a special-purpose language for analysing the questionnaires resulting from market research surveys. This language (Autostat) is an entirely declarative language by which the user can describe to the computer, in English, the nature of the replies to be expected in a questionnaire, and also ask questions of a selective nature, for example: how many people in certain age-groups smoke (a) pipes, (b) cigarettes (c) both and (d) neither? Such questions go hand-in-hand with class definitions describing the logical structure (if necessary by Boolean algebra) of the relevant age-groups in terms of the age-groups defined in the questionnaire. Dr Douglas was followed by Dr Yates of the Agricultural Experimental Station, Rothamsted, who described a very similar scheme for the more serious survey work, in medicine as well as agriculture, for which his statistical research group is responsible.

There was an account of a hydro-electric simulation on an Elliott computer. This related to a system consisting of two reservoirs, each with its separate catchment area, and a power house. Water can flow from the upper reservoir to the lower one through a tunnel, and is conducted from the lower one to the power house by another tunnel. (The scheme is operated by the British Aluminium Company.) The problem here is that there are highly seasonal fluctuations in the rainfall so that water spills over the dam of the smaller reservoir in winter, while in summer a load reduction has normally to be made in order to maintain sufficient reserve to avoid complete shutting down of the associated smelting plant. A mathematical model is used to study ways of operating the system and evaluating the gain in possible power production which might be obtained if some possible modifications to the system were effected, such as for example installing pumps in the tunnel connecting the small-capacity reservoir and the large-capacity reservoir.

Computer that stole the show

At this point it is worth digressing on the subject of the Elliott 803 computer, which was demonstrated at the conference and rather stole the show. It is a fully transistorized ferrite-core storage machine with a capacity of 4096 words (in the 804 version this can be extended to 8096 words). It need be switched on only when required and uses less than 1 kW on a single-phase 50- or 60-c/s supply. Owing to the lower power, little ventilation is necessary. The particular model being demonstrated was installed on the Sunday afternoon before the conference started, its attendants pointing out that it was working before the representatives of other manufacturers had set up their cardboard models! Other relevant facts about this machine are: a 40-bit word-length with fixed-point binary representation as standard, and a floating-point arithmetic as an optional extra; 5-hole paper tape is used as the input/output medium, although additional equipment is available to employ punched cards or 35-mm magnetic film. Any instruction other than multiplication or division takes 720 μs, while multiplication and division take up to 30 ms. But I was told that the floating-point attachment shortened the multiplication time to 7 ms. Dimensions of the machine are 4 ft 8 in. high by 5 ft 6 in. wide and 1 ft 4 in. deep.

Returning to the session on small computers, the last to be mentioned was the I.B.M. 305 Ramac. The installation at the Clark Shoe Company was described, where it is employed for stock control. The random-access facility of the magnetic-disk storage system provides access to any of 5,000,000 characters in 0·8 of a second. This is particularly useful when the stock levels of many thousands of different items have to be frequently updated.

The art abroad

In the first of the second day's sessions (' The State of the Art Abroad '), Mr Clarke of Elliott Bros. reported on his recent visit to Moscow with the 803 computer. Apparently this aroused great interest, so much so that at the exhibition where it was demonstrated even the man who drove the lorry had to be pressed into service to help explain the machine! He also described the Ural 2 and the B.E.S.M. 2 computers which his party had the opportunity to see. The audience gathered the impression that the Russians were four years behind in technical developments, and at present were doing their utmost to exploit the use of them rather than undertaking long-term research in components.

Dr S. Gill reported on his recent visit to the United States, where he attended the Western Joint Computer Conference. He told listeners that the I.B.M. Stretch computer, which has been widely advertised as the most powerful computing system under development, was to be delivered at Los Alamos in October 1960. This will have a multiplication time of about 2 μs, other operations taking about 1 μs, except for division which is 7½ μs. This is a very expensive machine, as may be seen from the fact that the Bureau of Standards were quoted a hire charge of 220,000 dollars per month for single-shift working, subject to a guarantee to use a certain minimum amount of time. Dr Gill gave the impression that there was very little work being done on logical design in American universities, except at Chicago and Illinois where work has been going on for the last three or four years on very-high-speed computing circuits.

Simulation

In the afternoon the conference split to discuss ' Numerical Analysis and Simulation Studies '. In the former session there were half a dozen contributions concerned with particular problems of numerical analysis, mostly in connexion with differential equations.

In the other session, there were three papers, the first by Mr Dempsey of Panellit Ltd., describing a special-purpose analogue computer for simulating the Berkeley Nuclear Power Station. Main interest here seemed to centre on the means by which the relatively long time-constants characteristic of certain nuclear reactions are obtained. Dr Youle (I.C.I. Ltd.) then described the simulation of a full-scale batchwise chemical plant, using a Ferranti Mercury. Simulation of all kinds of physical organizations (e.g., the hydro-electric application mentioned earlier) is proving to be a particularly fruitful field of application of digital computers, and a great deal of literature has been growing up around this subject in the last few years. The Chairman of this session, Dr K. D. Tocher, who has been in the forefront in developing sound statistical techniques for use in this connexion, made several amusing remarks in the course of the discussion concerning the effect of simulator programs on their writers, who became very attached to their ' plant ', defending it against attack, quoting performance figures etc. After a fortnight, said the Chairman, the behaviour of a program writer was in no way different from that of a plant manager!

A regular news-letter from CONTROL's special correspondents in the United States

Look at America

This month: bang-bang control—attitude—mass flow—jet relay—h.p. pneumatics

Relay or bang-bang control

In recent months several Americans reported on work with so-called relay or bang-bang control systems, all with the view of obtaining near optimum response and reducing system complexity. One of the simplest bang-bang control schemes appears in Fig. 1. The controller always exerts a maximum effort, either in the + or − direction, to bring the output into correspondence with the reference input, and the direction of the effort is sensitive only to the sign of the relay input. The presence of this 'bang-bang' characteristic means that the system gain will be very high when the amplitude of the relay input signal is small and it will be low when the relay input signal is large. In order to avoid step responses with excessive overshoot and/or steady large amplitude limit cycles, it is necessary to make the signal to the relay a function of certain time derivatives of the error as well as of the error itself.

For such systems the classical problem is that of finding the proper function of the error and its derivatives (*1*). This problem has been solved in a fairly general manner by phase plane techniques when only step inputs are considered. It is possible to predict how much of each derivative is necessary to bring the output to correspondence in the least time. For an n^{th} order monatomic process, it is necessary to use the first $n-1$ derivatives, each properly weighted for the given step input, in order to achieve optimum performance with the relay making $n-1$ reversals. Hence, a controller employing only the first derivative of the error can provide optimum control of a second-order process. In addition, even for a second-order process, the optimum combination of error and its first derivative (i.e., the switching function) varies depending on the size of the step input, load disturbance, initial conditions, etc.

A first step toward constructing a practical working system for controlling a second-order process is to choose a fixed weighted sum of the error and its first derivative as the switching function. Thus the switching function can be represented by a straight line in the phase plane. An ordinary differentiating network may be used as the function generator. Of course, care must be used in choosing the proper weighted sum of error and error rate to ensure near-optimum response (*2*). The method is applicable only to the control of over-damped (non-oscillatory) processes. More sophisticated systems employ a switching function in which the weighting of the error depends on the square of the error rate and appears as a parabola on the phase plane.

Another proposed scheme not only uses a straight-line switching function, but also can vary the saturation level of the relay output, or can even revert to proportional control (*3*).

The signal flow diagram in Fig. 2 shows that there are six possible combinations of inputs to the control selector. The following table describes the selector logic and what control mode is used for the possible combinations of error and error rate:

E	$E-K\dot{E}$	CONTROL MODE
+	+	Ordinary bang-bang
+	−	Bang-bang, but with level of output modified
0	+	Proportional
0	−	Proportional
−	+	Bang-bang, but with level of output modified
−	−	Ordinary bang-bang

There is considerably greater complexity required to provide the necessary logic, but the system is quite flexible and computer studies reveal that the system shows great promise.

The use of positive feedback around an ordinary bang-bang relay gives a device (Fig. 3) having rather useful properties (*4*).

Let $\theta_o/\theta_e \equiv \mu_e$ (a variable gain depending on θ_e) then

$$\frac{\theta_o}{\theta_i} = \frac{-1}{-(1/\mu_e)+K}$$

It is claimed that for very small signals, θ_e is small and μ_e is very large. Hence, as $\theta_i \to 0$, $\theta_o/\theta_i \to 1/K$, and the device is essentially a high-gain amplifier. When θ_i is large, however, μ_e is small, and the device acts as an ordinary relay. Such a scheme retains the advantages of relay control for large-amplitude signals, but has the notable benefit of eliminating, or at least greatly reducing, the limit cycle phenomenon when used as in Fig. 4.

The 'control function' provides the necessary computation for optimum switching during large signal operation, while the 'feedback function' contains the necessary stabilization networks required during small signal, linear operation. The overall configuration has been termed a 'dual-mode relay servo.'

The case of a second-order rate-type servo-motor (a third-order process) with bang-bang control was studied on an analogue computer (*5*), and compared with linear control for step inputs and sinusoidal inputs. The describing-function technique was used

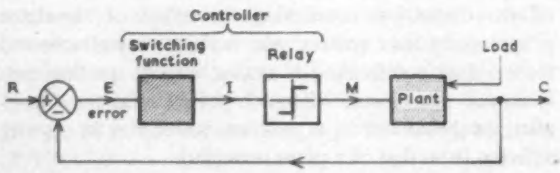


Fig. 1 Simple bang-bang scheme

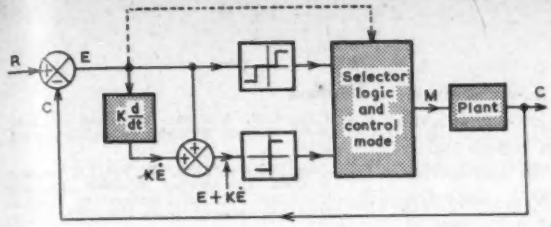


Fig. 2 Signal flow diagram

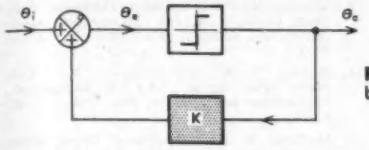


Fig. 3 Positive feedback round bang-bang relay

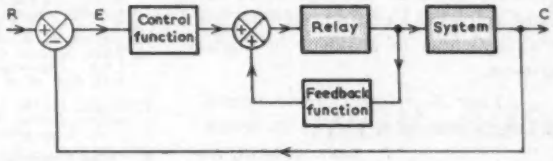


Fig. 4 Limit cycle phenomenon eliminated

to study the nature of limit cycle oscillations in this system. The speed of response of the bang-bang system was found to be of the same order of magnitude as that of a linear system for large input signals.

Space-vehicle attitude

In the area of specific hardware development, an interesting attitude control system has been developed for use in space vehicles (*6*). A combination of mass ejection, by means of reaction jets, and momentum exchange by means of reaction wheels, is used to control angular orientation. The mass ejection system operates from compressed helium that is stored within the vehicle. Simple on-off control is obtained by using solenoid valves at each of the jets. There is a purposely-designed dead space in the on-off relay, and it is in this region that the electric-motor-driven reaction wheel operates to give very precise adjustments in vehicle attitude. Since torques are applied to the vehicle only when the reaction wheel is accelerating, it is possible that the motor speed may become too high, in which case the pneumatic jets can be used to allow a reduction in motor speed.

Design provisions were made for three types of electric motors: an a.c. servo-motor, a d.c. permanent-magnet motor, and an electronically commutated d.c. motor. In the electronic power circuitry, on-off techniques are again used in order to eliminate quiescent power losses, and thus reduce the weight of batteries, etc. In the case of the d.c. motors, the signal is pulse-width-modulated to obtain speed control.

A single-axis prototype model incorporating this scheme has been constructed and tested satisfactorily.

Gyroscopic mass-flowmeter

Another interesting solution to the problem of measuring mass rate of flow has taken shape in the gyroscopic mass-flowmeter (*7*). Basically, the flowmeter consists of a vertically suspended circular fluid-carrying loop of tubing. The total angular momentum of the fluid in the loop about an axis normal to the plane of the loop is proportional to the mass flow rate. When the loop is vibrated about its vertical diameter, there results an oscillating gyroscopic precession

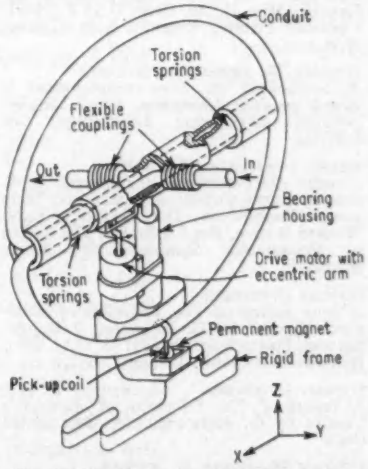


Fig. 5 The basic principle of the gyro-flowmeter can be seen from this diagram of an early form of instrument

torque about the horizontal diameter of the loop. This precession torque has the same frequency as the input vibration and an amplitude proportional to the mass flow rate of the fluid in the loop. Of practical importance is the fact that such an instrument is capable of measuring the mass flow of almost any material passed through it. Its manufacturer, the Decker Corporation, claims accuracies of better than ± 1% of full scale. (See Fig. 5.)

High-pressure pneumatics for wide temperature-ranges

In order to provide control over very wide ranges of operating temperatures, several research and development groups in the United States are working on high-pressure pneumatic control components and systems. Compressed gases or hot gaseous products of combustion serve as working fluids in these systems. Components currently being developed include control valves, servo-motors, amplifiers, signal generators, computers, transmission lines, reaction jet nozzles, and step-by-step actuators.

Some systems, intended for high-speed flight vehicles and space devices, are still on the design boards. However, some bread-board and prototype systems are already being tested or flown.

A recent special summer course in Fluid Power Control held at the Massachusetts Institute of Technology was attended by over sixty representatives from industry, many of whom are actively engaged in the development of high-pressure pneumatic systems. It was evident from many discussions both inside and outside the classroom that hot-gas systems are of very vital current interest.

Jet-type fluid relay

A considerable amount of publicity has appeared in the American techni-

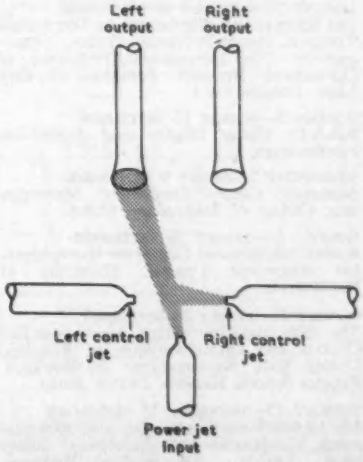


Fig. 6 Fluid amplifier as a digital device

cal press recently about a fluid relay scheme developed at the U.S. Army Corps' Diamond Ordnance Fuze Laboratory (*8, 9*). This device, which involves no moving mechanical parts, makes it possible to move a power jet with two or more low-signal-level control jets as shown in Figs. 6 and 7.

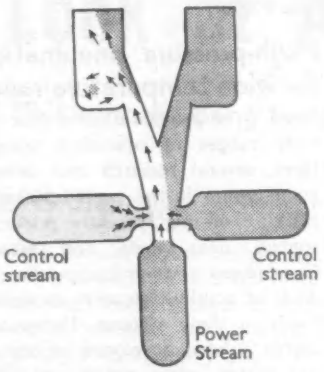


Fig. 6 Operation with very-low-pressure control stream

Power amplification in this device can be as high as 100:1, since the control jet requires only a fraction of the energy of the power jet. This amazingly simple device should make possible the inexpensive construction of a large variety of functional and logic devices such as *and* and *or* units, oscillators, flip-flops, and reaction controls. If units are combined, the fluid amplifiers can add, subtract, or multiply either as analogue or digital systems.

Your American Correspondents,
J. LOWEN SHEARER, ROBERT S. SCHER, KARL N. REID, JR.

Massachusetts Institute of Technology

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6. Froelich, R. W., and Patapoff, H.: 'Reaction Wheel Attitude Control for Space Vehicles', *I.R.E. Transactions on Automatic Control, 1959, Vol. AC-4, No. 3, p. 139.*
7. Decker, M. M.: 'The Gyroscopic Mass Flowmeter', *Control Engineering, May 1960, Vol. 7, No. 5, pp. 139-140.*
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9. Yeaple, F.: 'No Moving Parts for Fluid Amplifier', *Product Engineering, Mar. 14, 1960, Vol. 31, No. 11, p. 17.*

LOOKING AHEAD

Unless otherwise indicated, all events take place in London. B.C.S. British Computer Society. Brit.I.R.E. British Institution of Radio Engineers. I.E.E. Institution of Electrical Engineers. I.Mech.E. Institution of Mechanical Engineers. R.Ae.S. Royal Aeronautical Society. S.I.T. Society of Instrument Technology.

MONDAY 15—SATURDAY 20 AUGUST
11th Congress of the International Astronautical Federation. Stockholm, Sweden. Organizing Committee: IAF-60, Box 5045, Stockholm 5, Sweden.

MONDAY 29 AUGUST—FRIDAY 2 SEPTEMBER
Fourth London Symposium on Information Theory. Details: Professor Colin Cherry, Imperial College, Kensington, London, S.W.7.

WEDNESDAY 31 AUG—WEDNESDAY 7 SEPT
Annual meeting of the British Association for the Advancement of Science, Cardiff,

THURSDAY 1 SEPTEMBER
Joint Symposium on *Rocket and Satellite Instrumentation.* B.I.S. and S.I.T.

MONDAY 5—SATURDAY 10 SEPTEMBER
2nd International Conference on Operational Research. Aix-en-Provence, France. Organized by: The International Federation of Operational Research Societies, 11 Park Lane, London, W.1.

MONDAY 5—SUNDAY 11 SEPTEMBER
S.B.A.C. Flying Display and Exhibition, Farnborough.

WEDNESDAY 7—FRIDAY 9 SEPTEMBER
Automatic Control Conference, Massachusetts College of Technology, U.S.A.

MONDAY 12—FRIDAY 16 SEPTEMBER
A week's Residential Course on *Measurement for Automatic Control.* University of Nottingham.

MONDAY 12—FRIDAY 23 SEPTEMBER
The fifth Reactor School course on *The Control and Instrumentation of Reactors.* Durley Hall, Bournemouth. Applications: Reactor School, Harwell, Didcot, Berks.

TUESDAY 13—THURSDAY 15 SEPTEMBER
5th International Instruments and Measurements Conference and Exhibition, Stockholm. Details: AB Anders Beckman, Smalandsgatan 2, Stockholm.

WEDNESDAY 14—FRIDAY 16 SEPTEMBER
Congress of the Association Francaise de Calcul. Registration: The Secretary, Association Francaise de Calcul, Institut d'Astrophysique, 99 bis, Boulevard Arago, Paris 14.

THURSDAY 15—MONDAY 26 SEPTEMBER
22nd Radio, Television and Electronics Exhibition. Paris.

WEDNESDAY 21 SEPTEMBER—SATURDAY 1 OCT
Factory Equipment Exhibition, Belle Vue, Manchester. Industrial and Trade Fairs, Ltd., Russell St, Drury Lane, London, W.C.2.

MONDAY 26—FRIDAY 30 SEPTEMBER
I.S.A. Instrument-Automation Conference and Exhibition. Coliseum, New York.

TUESDAY 27—WEDNESDAY 28 SEPTEMBER
Symposium on *Automatic Control.* I.Mech.E.

TUESDAY 27—THURSDAY 29 SEPTEMBER
Conference on *Ergonomics in Industry.* Details: Miss H. M. Clay, D.S.I.R., 14–18 Cornwall Terrace, Regent's Park, London, N.W.1.

TUESDAY 27—FRIDAY 30 SEPTEMBER
A Symposium on *Flow measurement in closed conduit.* (Invitation only.) Details: National Engineering Laboratory, East Kilbride.

FRIDAY 7—SATURDAY 8 OCTOBER
Aviation Electronics and its Industrial Applications. Bristol College of Science and Technology. Registration: Hon. Secretary, South Western Section, Brit.I.R.E., c/o The School of Management Studies, Unity Street, Bristol, 1.

TUESDAY 11 OCTOBER
A brief survey of *The Principles of Automatic Control* by G. Heywood. 7.00 p.m. Borough Polytechnic. Details: G. L. H. Bird, Borough Polytechnic, London, S.E.1.

TUESDAY 18 OCTOBER
A repeat of *The Principles of Automatic Control* by G. Heywood. (See Tuesday 11 Oct.)

TUESDAY 18—FRIDAY 21 OCTOBER
First Effluent and Water Treatment Exhibition and Convention. Seymour Hall. Thunderbird Enterprises Ltd., 140 Cromwell Road, London, S.W.17.

WEDNESDAY 19—WEDNESDAY 26 OCTOBER
Interkama International Congress and Exhibition for Instrumentation and Automation, Düsseldorf.

TUESDAY 25 OCTOBER
Pneumatic Instruments in Process Control by N. Robertson. 7.00 p.m. Borough Polytechnic. (See Tuesday 11 Oct.)

LOOKING FURTHER AHEAD

TUESDAY 1 NOVEMBER
Automatic Control of Operations and Processes in the Ford Thames Foundry by K. H. Lee. 7.00 p.m. Borough Polytechnic. (See Tuesday 11 Oct.)

TUESDAY 8 NOVEMBER
Electronics in Process Control by C. G. Seeds and W. Barber. 7.00 p.m. Borough Polytechnic. (See Tuesday 11 Oct.)

TUESDAY 15 NOVEMBER
Automatic Control of Machine Tools by J. W. Smith. 7.00 p.m. Borough Polytechnic. (See Tuesday 11 Oct.)

MONDAY 21—WEDNESDAY 23 NOVEMBER
International seminar on *Analogue computation applied to the study of chemical processes,* Bruxelles. Details: R. Vichnevetsky, 43 rue de la Science, Bruxelles 4, Belgium.

TUESDAY 22 NOVEMBER
Automatic Control of Boiler House Plant by P. J. Wheeler. 7.00 p.m. Borough Polytechnic. (See Tuesday 11 Oct.)

TUESDAY 22—THURSDAY 24 NOVEMBER
Conference on electronic telephone exchanges. Details: The Secretary, I.E.E., Savoy Place, London, W.C.2.

TUESDAY 29 NOVEMBER
Automatic Control in the Steel Industry by M. H. Butterfield. 7.00 p.m. Borough Polytechnic. (See Tuesday 11 Oct.)

MONDAY 9—WEDNESDAY 11 JANUARY 1961
7th National Symposium on Reliability and Quality Control. Bellevue-Stafford Hotel, Philadelphia, Pa., U.S.A.

WEDNESDAY 15—FRIDAY 17 FEBRUARY 1961
1961 International Solid-state Circuits Conference. University of Pennsylvania and the Sheraton Hotel, Philadelphia, Pa., U.S.A.

MONDAY 27—FRIDAY 31 MARCH 1961
3rd National Symposium on Temperature, Its Measurement and Control in Science and Industry. Columbus, Ohio.

TUESDAY 9—WEDNESDAY 17 MAY 1961.
International Exhibition of Measurement, Control, Regulation and Automation (Mesucora) and 58th Exhibition of French Physical Society, C.N.I.T., Paris.

MONDAY 26 JUNE—SATURDAY 1 JULY 1961
International Measurements Conference, (Imeko), Budapest. Details: Prof. J. F. Coales, Cambridge University, Trumpington St., Cambridge, or Imeko Secretariat, Budapest 5, P.O.B. 3.

WEDNESDAY 4—THURSDAY 12 OCTOBER 1961
Second Electronic Computer Exhibition and Symposium. Details: D. C. Scoones, Peat, Marwick, Mitchell & Co., 94–98 Petty France, London, S.W.1.

Discussion of the mechanical side of servo-systems shows the relationship between the series damping of a two-lumped-inertia system and the damping coefficient of the quadratic lag

PART 2

Transfer-function manipulation may ease simulation

by **F. WALKER, B.SC.**
Manchester College of Science and Technology

In Part 1 last month we began by showing how to simulate three or four simple lags in one function unit. After this we took up the problem of reducing the number of feedback loops. Having dealt with complicated electrical loops, and back-e.m.f. and viscous-friction loops, we began a discussion of the simple mechanical system. This is continued below.

The easiest manner in which to simplify in this case is to manipulate the block diagram of Fig. 12b step by step as shown in Fig. 13. The transfer function of load position to motor torque is seen to be:

$$\frac{\theta_L}{T_M} = \frac{1}{J_T p^2} \cdot \frac{(1 + pT_1)}{(1 + pT_1 + p^2 T_1 T_2)}$$

The latter part of the transfer function is readily simulated with a bridged-T network in the feedback path of an operational amplifier. The time constants T_1 and T_2 determine the notch frequency of the bridged-T network, and this, of course, is the same as the mechanical resonance frequency [i.e. $(S/J_H)^{\frac{1}{2}}/2\pi$]. Two function units are required to simulate the whole transfer function, however, since a double integration is required in addition to the quadratic lag and simple lead. The double integration may be simulated as before; i.e. networks as shown in Figs. 2b and 2d at the input and in the feedback path, respectively, of an operational amplifier, and the two time constants made equal.

This, of course, assumes that a position control system is required to be simulated, since the transfer function of load position to motor torque has been considered. If, however, the system is a velocity control, the requisite transfer function is easily ascertained as it only entails a re-arrangement of one of the p factors in the denominator;

$$\text{i.e.} \quad \frac{p\theta_L}{T_M} = \frac{1}{J_T p} \cdot \frac{(1 + pT_1)}{(1 + pT_1 + p^2 T_1 T_2)}$$

Once again two function units are required if the restriction on components is to R's and C's. It is feasible, however, to achieve the above using only one operational amplifier with a very pure inductance at the input and a bridged-T network in the feedback path.

Unfortunately, this lumping together of transfer functions does not permit access to motor velocity, which term is required to simulate back e.m.f. It may be pos-

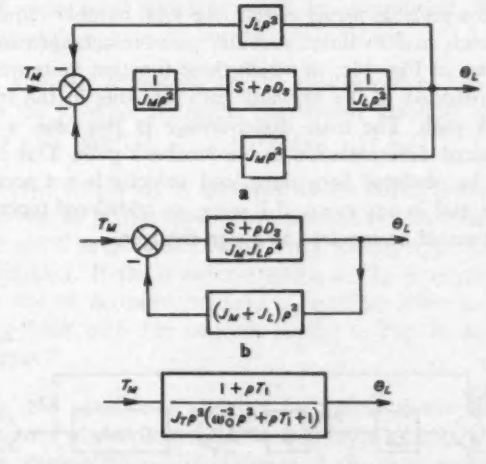

Fig. 13 Step-by-step manipulation of the block diagram of Fig. 12b. $T_1 = D_S/S \equiv 2\zeta\omega_0^{-1}$. $\omega_0^{-2} = J_H/S = T_1T_2$. $J_H = J_M J_L/(J_M + J_L)$. $J_T = J_M + J_L$.

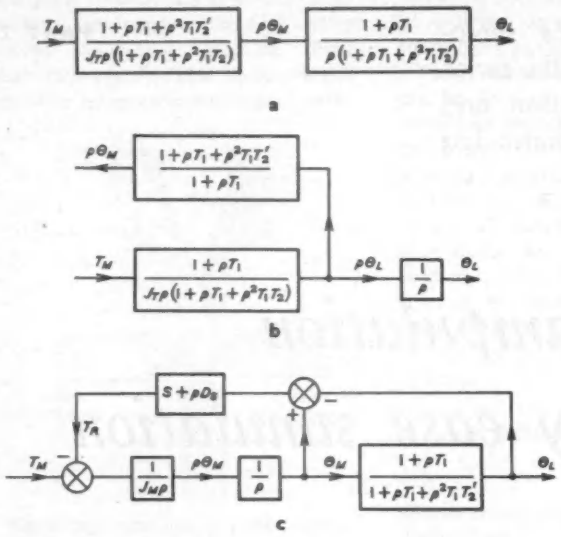

Fig. 14 Manipulation of block diagram to allow access to motor velocity $T_1T_2' = (\omega_0')^{-2} = J_T/S$. $J_T = J_M + J_L$. $T_1T_3 = \omega_0^{-2} = J_H/S$. $T_1 = D_S/S$. $J_H = J_MJ_L/(J_M + J_L)$

sible to ignore the back-e.m.f. effect in the majority of systems with motor field control, but this is certainly not permissible in the case of armature control. When motor velocity is required (to simulate back e.m.f., or perhaps to synthesize, in conjunction with armature current, motor voltage) there are two methods of approach, namely (i) to simulate the transfer function $p\theta_M/T_M$ and follow it with the transfer function $\theta_L/p\theta_M$; or alternatively, (ii) to derive motor velocity from load velcity by means of the appropriate transfer function. The two methods are indicated by the block diagrams of Figs. 14a and b. Both methods as shown require a minimum of four function units for simulation, excluding the possible requirements of a sign-changing amplifier in the feedback path. The use of a pure inductance where possible would reduce the total number required in each case to three. Another possible arrangement is shown in Fig. 14c, in which three function units would be required in the forward path and one in the feedback path. The main disadvantage in this case is the required differentiation in the feedback path. This cannot be obviated here since load velocity is not accessible; and in any event, if it were, an additional function unit would be required as a sign-changer.

Reduction of more complicated mechanical systems

If the viscous-friction torque at both the motor and load is not negligible, the mechanical system will have to be simulated as shown by the block diagram of Fig. 15. The most difficult case is shown, it being assumed that the viscous friction cannot be lumped at either the motor or load. If, however, such an assumption is permissible, the simplification of the block diagram is fairly obvious. The transfer function of the most difficult case relating load position to motor torque is derived in Appendix IV, but in order to reduce the degree of the denominator the following transfer function will be considered:

$$\frac{p\theta_L}{T_M} = (S + pD_S)/[J_MJ_Lp^3 + \{J_MD_L + J_LD_M + (J_M + J_L)D_S\}p^2 + \{D_MD_L + (D_M + D_L)D_S + (J_M + J_L)S\}p + (D_M + D_L)S]$$

The denominator of the above is a cubic in p, which will have only one negative real root and a pair of complex conjugate roots with negative real parts if the viscous friction is not excessive; i.e. the denominator could be factorized in a particular numerical case into a simple lag times a quadratic lag. If, however, viscous friction were excessive, the above denominator would degenerate to three simple lags, but this is highly improbable with the values of damping normally occurring in practice. A study of the transfer function reveals that the effect of the damping to ground at the motor and load is to add the terms D_M/J_M and D_L/J_L to the coefficient of p^2 corresponding to the coefficient of p in the case without parallel damping, and D_MD_L/J_MJ_L and D_TD_S/J_MJ_L to the coefficient of p corresponding to the constant term in the case without parallel damping. Thus it is the ratio of damping to inertia which is the governing criterion as to whether the complex conjugate pair degenerates to real roots. But it is the constant term D_TS/J_MJ_L which in normal circumstances mainly determines the location of the one real root, and consequently the total damping to ground is of primary importance in this regard. The other terms mentioned are of secondary importance in this respect, as the numerical example given in Appendix V indicates. From a root-locus viewpoint the effect of the total parallel viscous damping is to move one of the poles at the origin a short distance along the negative

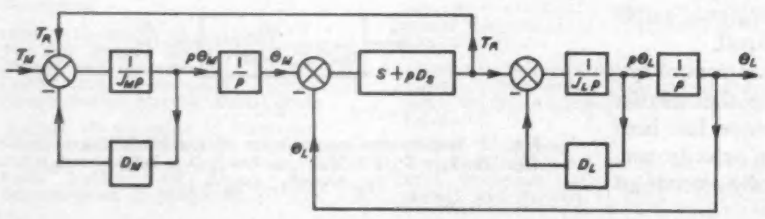

Fig. 15 Block diagram of mechanical system with viscous friction torque at motor and load shafts

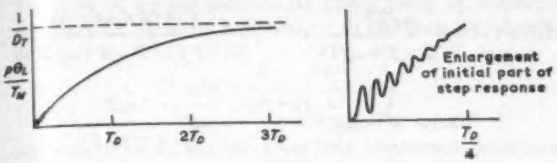

Fig. 16 Response of system velocity to a step of motor torque; i.e. for mechanical system similar to Fig. 15

real axis into the left-half p-plane, and very slightly increase the equivalent series damping.

The procedure for reducing the required number of function units could be the same as that described earlier; i.e. the mechanical system is set up on the analogue computer and subjected to a repetitive step input of torque. It is expedient to record load velocity rather than position since a steady-state value is obtained with the former. In this case the form of the transient response is not dictated mainly by the complex-conjugate pair of poles (as in the electrical case considered earlier) but by the real pole. The less the damping to ground, the greater is the contribution of the real pole. The example considered in Appendix V illustrates this point, the real part of the complex conjugate pair being approximately 33 times the value of the real root. A typical step response is shown in Fig. 16, in which the oscillation due to the complex conjugate poles is of relatively small amplitude, and dies out long before the steady state is reached.

It should be a comparatively easy matter to ascertain the exponential time constant from an oscillogram of the step response. Thus a fairly accurate value for T_D (the inverse of the real root) is obtained. Cascading the mechanical simulation with an operational amplifier having a bridged-T network at its input will, when tuned to the appropriate notch frequency, remove the oscillation superimposed on the step response. (Load velocity should be connected to the input of the bridged-T network). Sufficient information is now in hand to simulate fairly accurately the transfer function $p\theta_L/T_M$ using only one function unit, or θ_L/T_M using a minimum of two function units, by means of the techniques described earlier. A slight discrepancy arises if the suitably tuned bridged-T network, when connected in the feedback path of an operational amplifier, is assumed to simulate the correct simple lead and quadratic lag of the transfer function. The latter is correct within the limits of experimental accuracy, but the former is not quite correct—as the final transfer function of Appendix IV indicates. Nevertheless, the error incurred will be very small in the majority of cases; e.g. with the values quoted in Appendix V the error in T' would be + 5·1%.

Analytical approach

Fortunately, the labour of ascertaining the roots by calculation is not too great. If the denominator (ignoring the factor $J_M J_L$) is re-arranged in the form $(ap^3 + c) = -p(p^2 + b)$ a quick approximation to the one real root can be readily made. Then by Newton's method a more accurate assessment is easily obtained. On account of the exceptionally steep gradient at the real root, rapid convergence results, and in the majority of cases it will be sufficient to iterate once only, bearing in mind the degree of accuracy required.

Once the real root has been calculated, the quadratic factor is then obtained by dividing the denominator by the real factor. The two factors for the numerical example of Appendix V are shown graphically in Fig. 17. The product is also shown; i.e. the denominator apart from the scale factor $J_M J_L$. The steepness of the gradient at cross-over is clearly in evidence. In addition, it is obvious that the real root must be found before the complex roots can be ascertained, since the curve does not give any reasonable indication of the latter.

The real root has been obtained in Appendix V by an alternative procedure, however, which is based on the fact that the initial rate of increase of system velocity (or position) with damping to ground is the same as that without; i.e.

$$D_T \cdot T_D = J_T$$

This indicates very clearly the simplest manner possible for ascertaining the two factors, and consequently it is felt that a detailed explanation of the procedure in this case is unnecessary.

Once the three poles have been located it should be an easy matter to simulate the mechanical system. Unfortunately in this case, as pointed out earlier, the simulation of the lead factor, $1 + pD_S/S$, and the quadratic lag will not be as straightforward as the case without parallel damping, since the coefficients of p in the two factors are no longer identical; (the coefficient of p in the quadratic factor is now slightly greater). Consequently, the procedure to be adopted is as follows:

1. Connect a bridged-T network in the feedback path of operational amplifier with the appropriate time constants to give the correct quadratic lag;

2. Connect a network of the type shown in Fig. 2e at the input of the same operational amplifier with its time constant, $T' = D_S/S$ and $\alpha = T_1/T'$;

3. The simple lag is simulated in the normal manner by means of the appropriate parallel combination of R and C in the feedback path of a second operational amplifier. If the transfer function θ_L/T_M is required, it will be necessary to have a capacitor alone in the feedback path and network similar to Fig. 2b at the input.

It is thus possible to simulate by means of two function units what appears at first sight to be a rather complex mechanical system. Further, if the total damping to ground is not great it will be permissible to assume that the coefficients of p in the numerator and quadratic lag factor are the same, thus simplifying the simulation

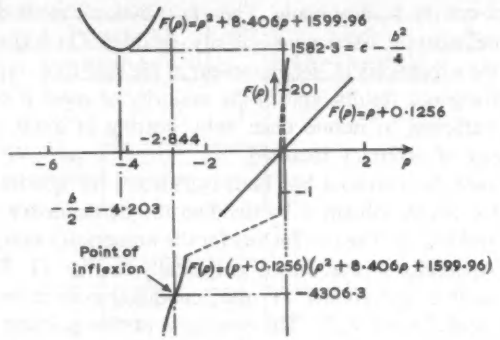

Fig. 17 Denominator (apart from the $J_M J_L p$ factor) for the numerical example of Appendix V shown graphically. Note the real and quadratic factors shown separately

to some extent. Once again, if access to motor velocity is required for feedback, the remarks made earlier are applicable in this instance also.

CONCLUSION

The prospect of simulating a fairly complex servo-system with a limited number of function units is considerably enhanced by using the techniques described. There appears to be only one real drawback, which exists mainly in the case of simplified feedback loops. That is, certain variables are no longer accessible after manipulation of transfer functions: but this difficulty is not insurmountable, and can be overcome by the methods described. The discussion on the mechanical aspects of servo-systems should be helpful to many, since it clearly indicates the relationship between the series damping of a two-lumped-inertia system and the damping coefficient of the quadratic lag; i.e. $D_S/S = 2\zeta/\omega_0$. The effect of parallel damping across the lumped inertias is to alter this relationship slightly so that $D_S/S < 2\zeta'/\omega_0'$

It will have been noted that in making comparison checks of simulations, the accent is on transient response and not frequency response, which is mentioned only briefly. Analogue-computer simulations lend themselves admirably to rapid comparison by means of step response techniques on account of the noise-free transients obtained. Although it is not in any way suggested that step response methods are more accurate than frequency response, they are considerably speedier, and with the advent of long-persistence, wide-angle cathode-ray tubes much greater accuracy is possible than hitherto.

APPENDIX I

(a) Unit step response of a simple lag and quadratic lag $(0 < \zeta < 1)$ in cascade, the transfer function of which is given by:

$$F(p) = \frac{1}{(1 + pT)(1 + 2\zeta\omega_0^{-1}p + \omega_0^{-2}p^2)}$$

$$f(t) = 1 - \frac{\omega_0^2T^2}{1 - 2\zeta\omega_0T + \omega_0^2T^2}e^{-t/T} + \frac{e^{-\zeta\omega_0 t}\sin(\omega_n t - \psi)}{[(1-\zeta^2)(1 - 2\zeta\omega_0T + \omega_0^2T^2)]^{\frac{1}{2}}},$$

where $\psi = \tan^{-1}\dfrac{(1-\zeta^2)^{\frac{1}{2}}}{-\zeta} + \tan^{-1}\dfrac{\omega_n T}{1 - \zeta\omega_0 T}$

and $\omega_n = \omega_0\,(1 - \zeta^2)^{\frac{1}{2}}$; i.e. $f_n = \dfrac{\omega_n}{2\pi}$, the natural frequency of the oscillatory transient response.

(b) Unit step response of two simple lags and a quadratic lag $(0 < \zeta < 1)$ in cascade, the transfer function of which is given by:

$$F(p) = \frac{1}{(1 + pT_1)(1 + pT_2)(1 + 2\zeta\omega_0^{-1}p + \omega_0^{-2}p^2)}$$

$$f(t) = 1 + \frac{\omega_0^2T_1^2}{(T_2 - T_1)(1 - 2\zeta\omega_0T_1 + \omega_0^2T_1^2)}e^{-t/T_1}$$

$$+ \frac{\omega_0^2T_2^2}{(T_1 - T_2)(1 - 2\zeta\omega_0T_2 + \omega_0^2T_2^2)}e^{-t/T_2}$$

$$+ \frac{e^{-\zeta\omega_0 t}\sin(\omega_n t - \psi)}{[(1 - \zeta^2)(1 - 2\zeta\omega_0T_1 + \omega_0^2T_1^2)(1 - 2\zeta\omega_0T_2 + \omega_0^2T_2^2)]^{\frac{1}{2}}},$$

where $\psi = \tan^{-1}\dfrac{\omega_n T_1}{(1-\zeta\omega_0 T_1)} + \tan^{-1}\dfrac{\omega_n T_2}{(1-\zeta\omega_0 T_2)} + \tan^{-1}\dfrac{(1-\zeta^2)^{\frac{1}{2}}}{-\zeta}$

and $\omega_n = \omega_0(1 - \zeta^2)^{\frac{1}{2}}$; i.e. $f_n = \dfrac{\omega_n}{2\pi}$, the natural frequency of the oscillatory transient response.

The second term of $f(t)$ in (b) is always negative provided $T_1 > T_2$, and the third term is always positive. If T_2 is reduced to zero and T_1 increased such that $(T_1 + T_2)$ remains constant, it is readily deduced that the initial rate of rise increases but so does the settling time (i.e. with respect to the exponential lags). The converse is likewise true. The argument holds also when the residues in the complex poles do not predominate.

APPENDIX II

$$\frac{p\theta}{E_G} = \frac{\dfrac{K_t}{JRp(1 + pT)}}{1 + \dfrac{K_tK_v}{JRp(1 + pT)}}$$

$$= \frac{1}{K_v} \cdot \frac{1}{\left(1 + \dfrac{JR}{K_tK_v}p + \dfrac{JRT}{K_tK_v}p^2\right)}$$

$$= \frac{1}{K_v} \cdot \frac{1}{(1 + pT_1)(1 + pT_2)},$$

provided that $\left(\dfrac{JR}{K_tK_v}\right)^2 > \dfrac{4JRT}{K_tK_v}$; i.e. $\dfrac{K_tK_v}{JR} < \dfrac{1}{4T}$

The roots of the denominator are simply found by expressing the quadratic in the form $(p^2 + bp + c)$ and using the formula:

$$p = -\frac{b}{2} \pm \left(\frac{b^2}{4} - c\right)^{\frac{1}{2}}$$

The reciprocals of the two roots thus ascertained correspond to the two time constants T_1 and T_2.

APPENDIX III

$$\frac{p\theta}{E_G} = \frac{\dfrac{K_t}{DR(1+pT)(1+pT')}}{1+\dfrac{K_tK_v}{DR(1+pT)(1+pT')}}$$

$$= \frac{1}{\left(K_v + \dfrac{DR}{K_t}\right)} \cdot \frac{1}{\left[1 + \dfrac{(T+T')}{\left(1+\dfrac{K_tK_v}{DR}\right)}p + \dfrac{TT'}{\left(1+\dfrac{K_tK_v}{DR}\right)}p^2\right]}$$

$$= \frac{1}{(K_V + K'_V)} \cdot \frac{1}{(1+pT'_1)(1+pT'_2)},$$

provided that $\left[\dfrac{T+T'}{1+\dfrac{K_tK_v}{DR}}\right]^2 \geqslant \dfrac{4TT'}{\left(1+\dfrac{K_tK_v}{DR}\right)}$;

i.e. $\dfrac{K_tK_v}{DR} \leqslant \dfrac{(T-T')^2}{4TT'}$

Note: (i) $\dfrac{K_t}{DR} = \dfrac{1}{K_v'}$ has the same dimensions as $\dfrac{1}{K_v}$ and $\dfrac{p\theta}{E_G}$; i.e. rad/sV.

(ii) $\left(1 + \dfrac{K_tK_v}{DR}\right) = F$; i.e. the d.c. forcing factor.

APPENDIX IV

$$\frac{\theta_L}{T_M} = \frac{\dfrac{(S+pD_s)}{(J_Mp+D_M)(J_Lp+D_L)p^2}}{1+\dfrac{(S+pD_s)}{(J_Mp+D_M)p}+\dfrac{(S+pD_s)}{(J_Lp+D_L)p}}$$

$$= \frac{(S+pD_s)}{p[J_MJ_Lp^3 + \{J_MD_L + J_LD_M + (J_M+J_L)D_s\}p^2 + \{D_MD_L + (D_M+D_L)D_s + (J_M+J_L)S\}p + (D_M+D_L)S]}$$

Alternatively, this transfer function may be simply obtained by substituting $(J_Mp + D_M)$ and $(J_Lp + D_L)$ for J_Mp and J_Lp, respectively, in the transfer function of Fig. 13c.

Reducing the coefficient of p^3 to unity,

$$\frac{\theta_L}{T_M} = \frac{(S+pD_s)}{J_MJ_Lp\left[p^3 + \left\{\frac{D_M}{J_M}+\frac{D_L}{J_L}+\frac{D_s}{J_H}\right\}p^2 + \left\{\frac{D_MD_L}{J_MJ_L} + \frac{(D_M+D_L)}{J_MJ_L}D_s + \frac{S}{J_H}\right\}p + \frac{(D_M+D_L)}{J_MJ_L}S\right]}$$

Otherwise, expressing in factorized form,

$$\frac{\theta_L}{T_M} = \frac{1}{(D_M+D_L)p} \cdot \frac{(1+pT')}{(1+pT_D)(1+2\zeta'\omega_o'^{-1}p+\omega_o'^{-2}p^2)}$$

$$= \frac{1}{D_Tp} \cdot \frac{(1+pT')}{(1+pT_D)(1+pT_1+\omega_o'^{-2}p^2)}, \text{ where } T_1 > T'$$

Note: $D_T \cdot T_D = J_T$
i.e. $(D_M + D_L)T_D = (J_M + J_L)$

APPENDIX V

$J_M = 12{\cdot}5 \times 10^3$ lb ft s^2 (referred to load shaft)
$J_L = 50 \times 10^3$ lb ft s^2
$J_H = \dfrac{J_MJ_L}{J_M+J_L} = 10 \times 10^3$ lb ft s^2
$S = 16 \times 10^6$ lb ft/rad
$D_S = 80 \times 10^3$ lb ft s/rad
$D_M = 6{\cdot}28 \times 10^3$ lb ft s/rad (referred to load shaft)
$D_L = 1{\cdot}57 \times 10^3$ lb ft s/rad

(i) $\dfrac{D_M}{J_M} = 0{\cdot}501$ (ii) $\dfrac{D_L}{J_L} = 0{\cdot}0314$

(iii) $\dfrac{D_S}{J_H} = 8$ (iv) $\dfrac{D_MD_L}{J_MJ_L} = 15{\cdot}73 \times 10^{-3}$

(v) $\dfrac{(D_M+D_L)D_S}{J_MJ_L} = 1{\cdot}004$ (vi) $\dfrac{S}{J_H} = 1{\cdot}6 \times 10^3$

(vii) $\dfrac{(D_M+D_L)S}{J_MJ_L} = 201$

Thus, apart from the J_MJ_Lp factor, the denominator of the transfer function θ_L/T_M is given by:

$$p^3 + 8{\cdot}532p^2 + 1601{\cdot}020p + 201$$

The above terms (i) and (ii) contribute only slightly towards coefficient of p^2; actually 6·2%. In addition, (iv) and (v) contribute even less towards the coefficient of p; actually 0·064%.

The combined motor and load exponential time constant due to damping to ground is readily obtained using the identity given in Appendix IV;

$$\text{i.e. } T_D = \frac{(J_M+J_L)}{(D_M+D_L)} = 7{\cdot}962 \text{ seconds}$$

The reciprocal of this value gives the numerical value of the one real root of the above portion of the denominator when equated to zero; i.e. $-0{\cdot}1256$. Adopting a first approximation of $-0{\cdot}125$ and applying Newton's method once only gives the remarkably close value of $-0{\cdot}1257$.

Thus, dividing through by the factor $(p + 0{\cdot}1256)$, the quadratic factor is obtained; the two factors are:

$$(p + 0{\cdot}1256)(p^2 + 8{\cdot}406p + 1599{\cdot}96)$$

It is of interest to compare the above quadratic factor with that obtaining when the damping to ground at both the motor and load is zero; i.e. $(p^2 + 8p + 1600)$. It is observed that the series damping has been effectively increased to the new value of $84{\cdot}1 \times 10^3$ lb ft s/rad (i.e. by 5%). The resonance frequency, on the other hand, has been reduced, but only infinitesimally by comparison ($\omega_o = 40$ rad/s, $\omega_o' = 39{\cdot}99$; i.e. by 0·03%). The effective series damping factor with damping to ground is $\zeta' = 0{\cdot}105$, whereas without damping to ground the series damping factor is $\zeta = 0{\cdot}1$.

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End

Television-receiver production at G.E.C. Coventry

Output is doubled and floor-space halved by bringing in automatic production methods

AN INCREASE OF 100% in output and a 50% saving in space are understood to have resulted from the introduction of automatic production methods at the General Electric Co.'s television receiver factory at Coventry, which CONTROL visited recently. Although closed-loop control as such is not employed, G.E.C. believe this production line to be the most highly-automated of its type in the world. It now provides a potential output of 5000 receivers a week, in half the production space previously needed, and has led to a reduction of one-third in direct labour charges—a benefit of particular importance in the Coventry area where labour costs are among the country's highest.

The key to the mechanized system is the use of printed wiring panels in the receivers, the boards lending themselves well to the breaking down of manufacturing processes into groups, a production method which would be difficult if the receivers were made up of large chassis.

Printed wiring

The process starts with copper-clad plastic boards being cut to size and pierced with two master holes to ensure accurate location of components during later stages. The boards are cleaned, sprayed with 'photo-resist' on the copper surface and placed under photographic negatives — which hold the 'circuit' — in printing machines. Boards and negatives are held together by vacuum and exposed to ultra-violet light. The unexposed photo-resist — the circuit—is then removed by a trichlorethylene spray to develop the board. The boards are then automatically conveyed through a machine which removes the unwanted copper, the latter being etched out by a ferric chloride spray, and the residual acid is washed off and the boards dried in an oven.

Brush scrubbers remove the remaining photo-resist (in order to prevent interference with soldering) and some 300 holes for mounting components are then punched. Next, the boards are degreased and selectively varnished so that only those areas of copper required for soldering are exposed. The reverse (plastic) sides of the boards have component reference numbers printed on them by a silk-screen process, for convenience in servicing.

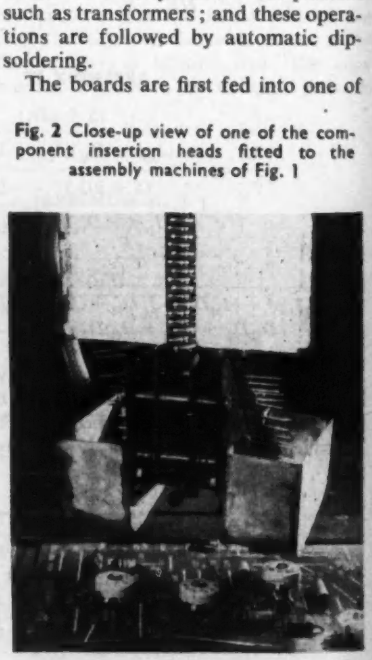
Automatic component insertion

Components and boards are assembled together in three operations: automatic insertion by indexing machines covers most of the resistors, valve holders and some capacitors; manual assembly covers components such as transformers; and these operations are followed by automatic dip-soldering.

The boards are first fed into one of

Fig. 1 These automatic assembly machines at the G.E.C. radio works, Coventry, insert components such as resistors and valve holders into printed wiring boards

Fig. 2 Close-up view of one of the component insertion heads fitted to the assembly machines of Fig. 1



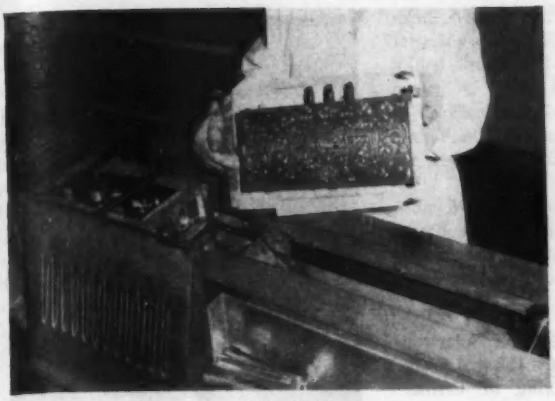


Fig. 3 A soldered board with its assembled components is removed from the automatic dip-soldering machine

the two rows of automatic assembly machines shown in Fig. 1. These incorporate indexing arrangements which progress the boards from station to station at intervals of a few seconds. At each station, up to four components are inserted by shearing the wires to the correct length, threading them through the holes in the panel and bending the ends over on to the copper surface. The magazines, loaded with about 250 components each, are replaced at regular intervals. A reservoir in the insertion head (Fig. 2) holds sufficient supplies to cover the magazine change-over time. At the completion of the automatic assembly the panels are released on to a moving belt which feeds the manual operators.

Mechanized dip-soldering

After inspection, the assembled panels are passed through a mechanical soldering machine (see Fig. 3). A steadily-moving chain-conveyor picks up each board presented to it and moves it through the fluxing and soldering stages. Flux is automatically sprayed on to the copper surface, followed by infra-red heating and drying. The panel is then allowed to float on a solder bath for a few seconds, after which it is shaken to dislodge any surplus. There is then a careful inspection of the soldering, followed by any necessary manual soldering, valves are fitted, and the panels pass to the testing machines.

Automatic testing

The equipment which tests the panel breaks down the work into a series of operations each of which takes about 25 seconds. The testing machine (Fig. 4) warms the valves up before testing to allow their performance to stabilize, and automatically positions panels at various stations. When an adjustment has to be made, automatic connexions enable the operators to start their work immediately a panel comes opposite them. The printed panels are inserted into a series of identical trolleys and connexions are made by spring-loaded plungers and plugs and sockets. The trolleys are indexed into the test positions by air cylinders, and automatic lifts are arranged at each end of the machine so that the trolleys circulate. Meters, cathode-ray tubes and frequency indicators are at eye level behind the trolleys with the operator's controls near at hand.

A card is attached to each trolley, and passes through a punching head at every station. If there is a fault, a relay automatically punches a hole in the card. At the end of the testing machine, unpunched cards show satisfactory panels, while panels requiring attention have cards showing the exact location of the fault.

From chassis to carton

The main production lines start with the metal chassis framework and finish with the receiver in its carton. Assembly operations are carried out on long indexing tracks which position the chassis in front of each operator in turn. The accurate location of the cathode-ray tubes is essential if the chassis is to fit the cabinet properly and a special jig worked by compressed air is used to ensure this. Manufactured items including printed panels, turrets, deflector coils and cable forms are fed to the appropriate positions by colour-coded trays on several conveyors. After the inspection and testing stages the chassis are fitted into cabinets which are supplied complete with protective glass from another overhead conveyor. Automatic lifts take sets which need rectification to a parallel line, from where they are returned to the first available space in the main flow.

Final test and clearance are followed by packaging, the cartons being prepared on an overhead gantry, dropped over the receiver, and inverted for sealing. A stapling machine adjusts automatically to fit various carton sizes for different models and staples the package, top and bottom, in one operation.

Electronic timing

The timing of all the manufacturing operations, with the exception of automatic assembly, is synchronized by an electronic control system designed and made in the works. Based on Dekatron decade counters the system co-ordinates the speed of operation of the various lines, and switches them on and off automatically to cover starting and stopping at the beginning and end of the working day, meal times and other breaks. It provides the initial electrical impulses for controlling the operation of every mechanism.

All in all, CONTROL was quite impressed with this near-flow quantity production of a complex piece of domestic equipment, in spite of the fact that control engineering techniques were not employed to any great degree. Strictly, these production lines are not 'fully-automated' but they do employ mechanical handling and mechanized assembly techniques of some interest. A great deal of manual labour—some 400 women—appears to be employed, but for all that it is still the world's most highly automated television assembly line. The television-receiver manufacturer's problems are seen in greater perspective when it is appreciated that every set incorporates about 300 components, 750 soldered joints, sixteen to twenty valves, and fifty tuned circuits. A system which can produce 5000 such receivers a week is not to be disparaged.

Fig. 4 Assembled printed panels are passed through this automatic testing machine, any faults being indicated by holes punched in cards

PEOPLE IN CONTROL

by Staffman

ROSENBROCK et al
Retreat from Moscow

The weary travellers in my heading illustration are British delegates in flight from the Ifac Congress in Moscow (see page 84 ff.). This photograph does suggest the heavy strain which attendance at a major international convention entails nowadays. **H. H. Rosenbrock** of C.J.B., whom you may recognize more readily from his photograph on page 83, is among the many who give me the impression that it was not all vodka, caviare and culture.

By the way, I hear that **John F. Coales,** leader of the British delegation, had to pour oil on troubled waters at the Ifac Congress. Apparently Professor **Rufus Oldenburger** of Purdue University got so cross with the Russians that he sprang an unofficial press conference. He told lay journalists that the U.S.S.R. was threatening to leave Ifac unless Russian proposals for its future organization were accepted. Coales countered with another press conference where, supported by **Harold Chestnut** and **V. A. Trapeznikov** (American and Russian Ifac men), he admitted disagreements and denied any ultimatum. Most people will I think heartily agree with Coales' fight to keep politics out of Ifac. Incidentally, several delegates have praised the behind-the-scenes work of Professor **G. D. S. MacLellan** of Glasgow University, who was deputy to Coales.

Sima's Council for 1960–61 has been elected, **G. C. Ottway** of W. Ottway and Co. becoming President, the retiring President, **L. A. Woodhead** of Cossor Instruments, automatically becoming a Vice President. **A. W. Jones** of Fleming Radio is also a Vice President, **A. W. A. Rundle** of A. Gallenkamp is Hon Treasurer, and **E. R. Ponsford** of Solartron is Hon Secretary. The new Council members are **S. T. Pickering** of Chance Pilkington, **G. M. Sisson** of Sir Howard Grubb Parsons, **G. S. Sturrock** of Kelvin & Hughes (not to be confused with **G. M. Sturrock** of Ultra Electric), and **R. Foxwell** of Wayne Kerr. Richard Foxwell, of course, is Wayne Kerr's Managing Director: he founded that company in association with **Raymond Calvert** in 1945.

The Institution of Electrical Engineers has also settled on its Council and Officers for 1960–61, under the Presidency of Sir **Hamish D. MacLaren**, the Director of Electrical Engineering at the Admiralty, Bath. The vacancies on the I.E.E.'s Measurement and Control Section Committee have been filled by **C. G. Garton** of E.R.A. (Chairman), **W. S. Elliott** of I.B.M. and **A. J. Maddock** of B.S.I.R.A. (Vice Chairmen), and **S. S. Carlisle** of Bisra, **C. A. Laws** of Elliott Brothers, **W. J. Jefferson** of the London Electricity Board and **F. C. Widdis** of Northampton C.A.T. (Ordinary Members of Committee).

There appears to have been some reshuffling at Honeywell Controls: **G. A. Jones** has been appointed Manager of the Contract Supervision and Installation Department—in general he will be concerned with the larger contracts; **E. S. Milk** becomes Manager of Industrial and Scientific Export Sales—he will co-ordinate British Honeywell's export activities with those of foreign Honeywell companies; **A. Stephens** becomes Senior Flow Engineer; and **R. W. H. Vivian,** will specialize in application engineering. Stephens has extensive knowledge of flow and other instrumentation. He was with Humphreys & Glasgow on the Chesterfield underground gasification project for two years, spent two years at Honeywell as instrumentation contracts engineer, fifteen months with George Kent, and four years with Electroflo, apart from a four-year apprenticeship with the Ministry of Supply.

Honey well served by

JONES MILK STEPHENS VIVIAN

I am told that **John P. Minister,** who has just been appointed General Sales Manager of Measuring Instruments (Pullin) is well known in the aircraft and electrical instrument industries. He was, of course, London Instrument Manager of Sangamo Weston. I gather that Minister's new appointment will not affect **S. H. Hughes'** position as Sales Manager of M.I.P.'s instrument division.

Don Peters, Chief Industrial Engineer of U.S. Hughes Aircraft's International Division, is now at Glenrothes, Fife, supervising the installation of equipment in a new plant for Hughes International (U.K.) Ltd. The new company will manufacture semiconductor components—diodes mainly—under **David Simpson,** its General Manager. Simpson says 'We are trying as far as possible to use Scottish staff and it will certainly be an all-British staff.'

English Electric have acquired a most distinguished director for the boards of their subsidiaries, Marconi's Wireless Telegraph, Marconi Instruments, English Electric Valve, and the associated company Marconi International Marine. He is **Sir Gordon Radley** who has just re-

tired from the position of Director General of the Post Office.

I gather from Cambridge Instrument that there was 100% acceptance of their offer to the shareholders of Electronic Instruments, and the merger between the two companies has been completed. **Paul Goudime,** Managing Director of Electronic Instruments, has joined the board of Cambridge Instrument, and **P. Dunsheath,** Chairman of Cambridge Instrument, **Mr. H. C. Pritchard,** Managing Director and **W. E. Lamb,** Director, have joined the Board of Electronic Instruments. **A. C. W. Norman** will continue to be Electronic Instruments' Chairman, with **Paul Goudime** as Managing Director, and **D. A. Pitman** as Sales Director.

Sir **Willis Jackson,** Director of Research and Education of A.E.I. (Manchester), is to return to academic life as Professor of Electrical Engineering at Imperial College. He is, of course, a former apprentice of the old Metropolitan-Vickers Electrical Company and resigned his Chair at Imperial College some seven years ago to become their Director of Research and Education. I gather from A.E.I. that a primary object of their policy has always been to maintain the closest relations between the Electrical Industry and the Universities. They feel that Sir Willis Jackson's return to academic life should cement these bonds.

AUTHORS IN CONTROL

John G. Truxal (*The meaning of Ifac: eagle's-eye view of the Congress,* page 85), the well-known American control engineer, received his education at Dartmouth College (A.B. in 1943) and Massachusetts Institute of Technology (Sc.D. in 1950). From 1950-54 he served on the faculty of the School of Electrical Engineering at Purdue University, and then joined the faculty of the E.E. Department at the Polytechnic Institute of Brooklyn. In 1957 he became the Head of the Department. Dr. Truxal is the author of *Automatic feedback control system synthesis* (McGraw-Hill, 1955), editor of *Control engineers' handbook* (McGraw-Hill, 1958), and co-author with W. A. Lynch of the forthcoming *Principles of electrical engineering* (McGraw-Hill, February 1961). A consultant to several industrial organizations in control, Chairman of the A.I.E.E. Feedback Control Systems Committee, the I.R.E. Professional Group on Education and the A.A.C.C. Control Theory Committee, he is also a member of the A.A.A.S., Eta Kappa Nu, Tau Beta Pi, and Phi Beta Kappa.

WESTCOTT

FOWELL

J. H. Westcott (*The meaning of Ifac: overboard with frequency response,* page 87) was educated at London University, and an engineering apprentice at B.T.H., Rugby, from 1937 until he joined the Radar Research Establishment in 1942. He was a research student at Imperial College from 1946-50, during which period he was a 'guest' of the Massachusetts Institute of Technology for one year. In 1950 he became Lecturer in the Electrical Engineering Department at Imperial College; since 1957 he has been Reader in Automatic Control. Dr. Westcott has been a Member of the Councils of the I.E.E. and the S.I.T. and a Consultant to A.E.I., Shell and the Ministry of Aviation. He is CONTROL's Consultant on systems, and is the author of 28 publications on automatic control—for the most part on the theory of linear control systems with, recently, emphasis on the statistical analysis of signals and statistical problems in connexion with control system design.

R. J. A. Paul (*The meaning of Ifac: digital computer control,* page 90). See page 131, April 1960.

R. J. Redding (*The meaning of Ifac: gulf between theory and practice,* page 92) was an apprentice at Elliott Brothers (London) Ltd. whilst studying at South East London Technical College and elsewhere. He became involved in telemetry and remote control just after the war. These interests led to activities in pioneering electronic process control. He joined Evershed and Vignoles as a development engineer in 1951, when electronic process control was just coming into practical use, and is now Chief Technical Engineer of that company's Instrumentation and Controls Division. He became a Member of the I.E.E. last year.

D. B. Foster (*The meaning of Ifac: these are the practical needles in the theoretical haystack,* page 93) was educated at King's College, London. From 1929-36 he was a research engineer at Western Electric, and held a similar position with Vauxhall Motors until 1942 when he became Assistant Director of the British Coal Utilisation Research Association. Dr. Foster was General Manager of the Powell Duffryn Research Laboratories and Technical Director of Powell Duffryn Carbon Products until 1950, and a Director of Mullard Equipment until 1957. At present he is an independent Consultant on automation. A Member of the I.Mech.E., the I.E.E., the I.Chem.E., and a Fellow of the Institute of Fuel, Dr. Foster is also Chairman of the Scientific Committee of the Engineering Industries Association.

E. J. C. Fowell (*More control on machine tools,* page 97) started his career with Marconi's Wireless Telegraph Company in 1952 as a member of a ground-radar development group. Later, on joining the Ministry of Supply (as it was then), he led a small team working on the instrumentation of ballistic trials. In 1957, on leave from his department, he moved to the College of Science and Technology at Manchester to participate in a research project concerned with the performance of profiling machine tools under numerical control. Returning to the Ministry of Aviation in 1959, his main preoccupation is still with machine-tool control.

A. J. Sadler (co-author with P. A. Turner —below—of *The silicon controlled rectifier,* page 101) graduated in physics from King's College, London. He joined A.E.I. (Rugby) four years ago and has been working in its Research Laboratory on high-power silicon rectifiers and, more recently, on controlled rectifiers.

P. A. Turner was born in Canada where he received part of his education. He joined the A.E.I. in 1946 as a draughtsman. After obtaining his H.N.C. in electrical engineering at Rugby College of Technology and Arts, he joined the A.E.I. (Rugby) Research Laboratory as a research engineer. There he has been associated with the development of low- and medium-power germanium and silicon rectifiers and, more recently, has been working on the development of a medium-power controlled rectifier.

R. A. Brooker (*A lull in computers,* page 108). See page 119, March 1960.

F. Walker (*Transfer-function manipulation may ease simulation—2,* page 113). See page 125, July 1960.

A monthly review—under basic headings—of the latest control engineering developments for all industries; specially edited for busy technical management, plant and production engineers, chemical engineers, etc., who are not specialized in instrument and control systems

IDEAS APPLIED . . .

. . . to STRAIN

High-temperature extensometer

An air-jet directed at a plane surface, and fed from a restricted air supply, is commonly used to give an indication of the clearance between the jet and the surface. For very small clearances, air pressure upstream of the jet is approximately proportional to the reciprocal of the clearance. This principle has previously been used for an extensometer working at constant temperature, but at elevated temperatures it is difficult to apply because of the differential expansions of various parts of the mechanism.

An extensometer under development at the R.A.E. incorporates a number of departures from normal air-gauge practice to make it suitable for use on structures at high temperatures. It represents an attempt to break away from the conventional resistance strain gauges, which have serious defects in this application.

Air-gauging equipment normally uses pipes of relatively large diameter and air pressures in the region of 10 lb/in². The R.A.E. instrument uses very small bore tubing, and nitrogen, instead of air, at pressures of the order of 100 lb/in². Nitrogen was chosen to prevent oxidization when working at high temperatures. To avoid errors due to temperature variations, the instrument compares a short length of the structure under load with that of an equivalent length of tubing of similar material at the same temperature. As the tubing is not subjected to load, and has the same coefficient of thermal expansion as the test piece, a true indication of extension due to stress is obtained.

Fig. 1 shows the arrangement used. The supply pipe divides into two similar legs at *A*, both legs being welded to the test piece between *A* and *B*. At *B* the supply pipe is brazed to a second pipe which leads to the nozzle *C* and to the measuring gauge P_2. An internal port gives direct communication between the two pipes. By welding the piping to the test piece between *A* and *B*, and using small bore tubing (0·6 mm o.d.) for this part of the system, the nitrogen is raised to the temperature of the test piece. The gauge piece, *BC*, which is approximately 0·2 in. long, is heated by the nitrogen, and consequently also follows the temperature of the test piece. The plane surface *E*, at which the nozzle is directed, is also welded to the test piece.

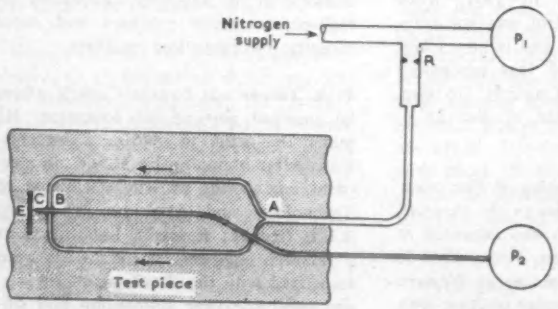


Fig. 1 Schematic diagram of R.A.E. extensometer. The two branches of the supply pipe between A and B are welded to the structure, to ensure that the nitrogen reaches the temperature of the structure before entering the gauge piece BC

As flow is dependent on the fourth power of the diameter of the pipe, relatively high pressures are necessary. Further, because of the small pipe diameter and the variation of temperature along its length, the pressure drops between the restriction and the nozzle are neither negligible nor constant. Errors from this cause are obviated by (1) designing the system to give constant mass-flow and (2) connecting the final pressure indicator P_2 by a separate 'static' pipe to the point *B*, very close to the exit nozzle *C*.

Constant mass-flow is assured by using a gas supply at constant temperature and pressure, and a fixed orifice at *R*, working under 'choke' conditions, i.e. with a ratio of at least 1·89 between upstream and downstream pressures. To ensure independence of the atmospheric pressure (though this is not considered to be of great importance) the nozzle orifice is also operated under 'choke' conditions.

For precise calibration, the temperature of the gas passing through the nozzle must be known. This information is given by a thermocouple attached to the surface. The law governing flow through the nozzle is $M = Cap/T^{\frac{1}{2}}$, where A = mass-flow, C = orifice coefficient, p = upstream pressure (measured on the gauge P_2), T is the absolute temperature, and a is an approximately linear function of the displacement. As C depends on T,

this may be written:

$$\text{Displacement} = \frac{k}{p}\text{f}(T), \text{ where f}(T)$$

and the constant k are determined by calibration. The dependence on T is relatively slight, a change of 900°C being required to alter the pressure p by a factor of two, for a given displacement.

Extensometer using moiré fringes

Another recently developed high temperature extensometer uses the moiré fringe technique (briefly explained below) and records extension. Unlike the R.A.E. instrument, this equipment is designed primarily for creep tests on standard specimens. It incorporates a means of compensating for the differential expansion of opposite sides of the test pieces.

The test pieces are machined with collars near each end, to support the arms which transmit the motion to the moiré fringe equipment. Each collar supports an L-shaped arm on each side of the test piece. The lower ends of these arms are constrained to move only in the direction of the applied force, and each pair is connected by a cross link carrying a diffraction grating (see below) at its centre. This arrangement ensures that the movement of each diffraction grating equals the average movement of the specimen cross-section to which it is connected.

The moiré fringe signals produced by relative motion of the two gratings are picked up by a Ferranti optical reading unit, which, through an amplifier and two-phase motor, drives a linear pen recorder.

Diffraction gratings are actually flat strips of glass with a large number of closely-spaced opaque lines on them, ruled perpendicular to the length of the strip. When one grating is moved longitudinally relative to the other, the lines on the two gratings being not quite parallel, dark longitudinal fringes—moiré fringes—move across the gratings.

This equipment was developed by A.I.D. Laboratories and Ferranti, and patents have been applied for.

. . . to LEVEL

Reflecting-prism detector

A light-operated level-sensing device, making use of the internal reflecting properties of a prism, is being developed by Normalair. Comprising one unit only instead of the usual two, the device overcomes some of the disadvantages of the conventional optical level detector. It is independent of the degree of transparency of the fluid, and of the dimensions of the tank.

The principle of operation is as follows. Rays from a light source are directed down one side of a transparent probe. The end of the probe is made in the form of two plane surfaces with an included angle of 90°. If the prism is surrounded by air, the light suffers double internal reflexion and is transmitted back through the other side of the probe to a light-sensitive cell. When the prism is in a liquid, the respective indices of reflection of the probe material and the liquid are such that the light passes through the surface instead of being reflected.

The probe is normally of transparent plastic, though other materials are being considered for fluids which may attack the probe. It has been found that with this particular probe material and prism angle, total internal reflexion occurs in air and other gases, while in practically all liquids the light is transmitted through the surface.

. . . to SPEED

Mechanical variable-speed gear

An infinitely variable reduction-gear, based on wedging-roller-type freewheels, has recently been introduced by Fairbairn Ulro of Leeds. The drive is transmitted through the gear by entirely mechanical means, and, being independent of the properties of fluids or friction linings, it is claimed that the new unit is not affected by changes in environmental conditions.

The essential parts of the mechanism are shown in Fig. 1. A rocker, C, is operated by the cam B_1 on the input shaft A. Motion is transmitted via the roller H to the arm D, which is attached to the inner part E of a freewheel. The rocker C and the arm D are spring-loaded to maintain contact between the various parts of the mechanism.

A reciprocating motion is thus imparted to E, which, because of the action of the wedging-roller mechanism, exerts a discontinuous uni-directional torque on the outer ring F of the free-wheel. This ring is connected to the output shaft. A duplicate mechanism, driving another similar freewheel, is operated from the cam B_2, which is set on the input shaft at 180° to B_1. The design of the two cams is

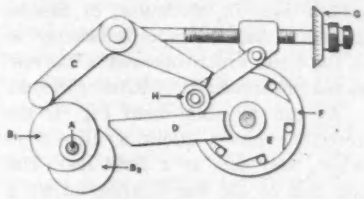


Fig. 1 Essential parts of the variable-speed mechanism. The drive is transmitted through the linkage from the input shaft A to the outer ring E of the free-wheel

such that steady rotation of the output shaft results. Adjustment of the output speed is by the manual control G, which determines the position of the roller H relative to the arm D, and can be adjusted while the gear is in operation.

Known as the 'Contorq', the unit is designed for a maximum speed of 450 rev/min, and for a maximum output torque of 2520 lb in. over the entire speed range. The reduction ratio is variable between 9 : 1 and infinity.

. . . to FLOW

Transmitter operated by fluid impact pressure

The newly-introduced Foxboro 'Target' meter has been designed to measure flow of liquids, such as heavy hydrocarbons, which because of their high viscosities are difficult to measure with existing types of instruments.

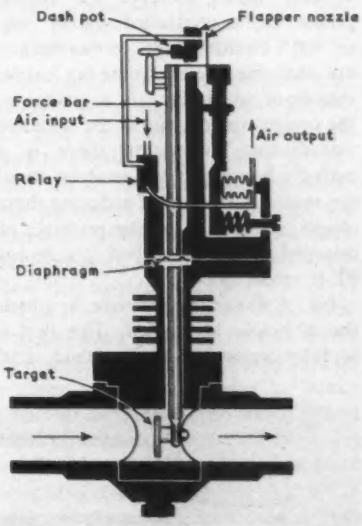


Fig. 1 Cross section of the transmitter

The principle used is to measure the force exerted on a disk positioned centrally in the pipeline, in a plane normal to the direction of flow. The disk (which is, of course, of smaller diameter than the pipe) is attached to a force-bar which operates a conventional pneumatic force-balance system.

As can be seen from Fig. 1, the force-bar pivots about a diaphragm which also acts as a fluid seal. The top end of the bar is attached by a flexible metal band to a flapper and to an adjustable balance arm. This flapper operates with a nozzle in the usual way, the pressure in the nozzle line being fed back to a bellows which opposes the motion produced by the force bar, and restores the position of the balance arm. Output pressure is proportional to the force exerted by the force-bar, this being proportional to the square of the velocity of the fluid striking the 'target'. Thus the output of the transmitter, which is in the 3–15 lb/in² range, is proportional to the square of the rate of flow.

An oil-filled piston-type dashpot damps the motion of the force bar, so that 'noise' in the system will not be amplified by the flapper-nozzle mechanism.

. . . to TEMPERATURE

Improved on-off control

H. SUTCLIFFE, *University of Bristol*

One of the simplest methods of controlling temperature is to use a temperature-sensitive element, such as a thermal expansion device, to operate a relay which switches the heating power to the controlled system 'on' or 'off'. Disadvantages of this method are that the thermal time-lag causes overshoot when there is a change in the control setting, and in the so-called 'steady-state' condition there is a periodic hunting of temperature about the mean. A method of reducing these effects, referred to as 'the principle of reversed lag', is described in a recent I.E.E. paper (*1*).

Fig. 1 illustrates a device in which the principle is applied. The device is fully immersed in the fluid, and would be wholly at the temperature of the fluid, if this were not varying with time. The setting of control contacts C_1 and C_2 is adjusted so that, under steady conditions, they just touch when the temperature is at the desired value. *ABD* is a bimetal strip having the metal with the higher expansion rate on the lower side between *A* and *B*, and on the upper side between *B* and *D*. The control contacts and the portion *BD* of the strip are inside a sealed enclosure, the strip being supported at the point *B* by the flexible diaphragm *F*.

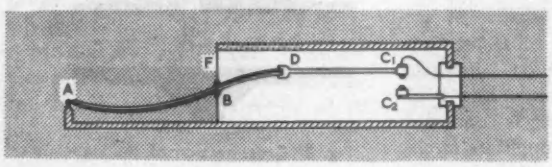


Fig. 1 Modified temperature sensitive element

Suppose first that the reversed section were not present, and that the contacts were set for some value T_0 of the fluid temperature T. As the fluid is heated from cold—say by an electric immersion heater—the fluid temperature T will lag behind that of the heater element. When T_0 is reached, and the power is switched off, heat from the element will continue to flow to the fluid and cause an overshoot of temperature T above T_0. The system will finally reach a 'steady' state, with T executing cyclic fluctuations about T_0. The initial overshoot, and the cyclic fluctuations, may exceed acceptable limits in some applications. The object of the short reversed section of bimetal strip is to reduce the amplitude of both overshoot and cyclic-fluctuations.

Consider now the same situation as before, but with the reversed section present, the setting of contacts C_1 and C_2 being such that they would just touch if both sections of the bimetal strip were at temperature T_0. The external section *AB* is in intimate contact with the fluid, and may be assumed to be exactly at temperature T. The reversed section however is within an enclosure, and receives heat mainly by conduction along its length, so that its mean temperature lags behind T in time. As a result, when T is increasing during initial heating, the position of C_1 is higher than would be the case if the whole system were at a uniform temperature T. Consequently the contacts open before T reaches T_0, and the overshoot which was present with the unmodified system can be avoided or reduced.

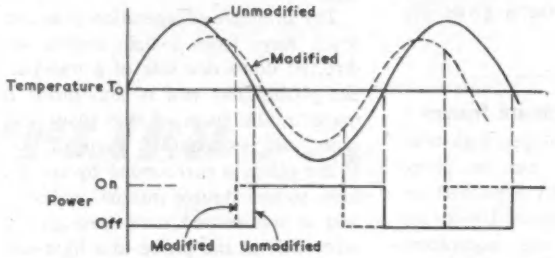


Fig. 2 Temperature fluctuations and corresponding power switching waves of the modified and unmodified systems

The amplitude of the fluctuations of T in the 'steady' state will also be reduced. The effect of the modification to the measuring element is to advance the phase of the power switching operation relative to temperature fluctuations, as shown in Fig. 2, and to increase the switching frequency. In terms of frequency response, the new condition is represented by the point *B* on the curve (Fig. 3), while *A* represents the condition when an un-modified measuring element is used. (The curve *CAB* is obtained by subjecting the system to continuous on/off cycles of power input at a number of distinct frequencies. For the frequency represented by the point *P*, *OP* represents the amplitude of the resulting temperature fluctuations, and ϕ the lag between the power input wave and the temperature wave).

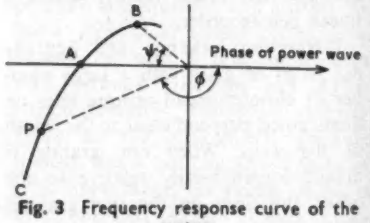


Fig. 3 Frequency response curve of the system

The paper referred to (*1*) gives a fuller account of the principle of 'reversed lag', and discusses the thermal responses to sinusoidal temperature fluctuations of a number of arrangements of temperature sensitive elements. The data are presented in such a form that an optimum design can be reached for the 'steady' state for a

given system. The possible improvement clearly depends on the characteristics of the system concerned. A reduction of fluctuation to less than half is reported in a typical application.

1. Sutcliffe, H. 'The Principle of Reversed Lag Applied to On-Off Temperature Control', Paper 3190M, *Proc. I.E.E.*, Vol. 107, B, No. 32, March 1960.

Derivative action from thermal lag

A further interesting application of a lagged measuring element is the subject of a recent English Electric patent (British Patent No. 835,551). The object of the device is to produce a derivative signal for a temperature control system.

Referring to Fig. 1, R_1 and R_2 are two resistance-thermometer elements which are similar except that R_2 is thermally lagged. R_3 and R_4 are equal

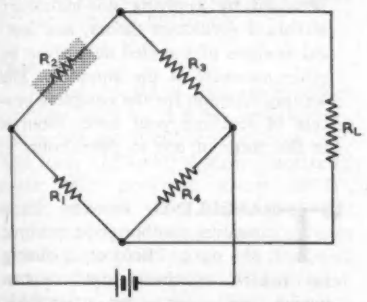


Fig. 1 Bridge circuit. R_1 and R_2 are resistance thermometer elements, R_2 being thermally lagged

resistances, so that, when the two measuring elements are at the same steady temperature, the bridge output is zero.

Both elements are immersed in the medium being controlled. When the temperature changes, the response of the element R_2 lags behind that of R_1, by an amount dependent on the rate of change of temperature. The bridge output at a given temperature depends only on this rate of change. Normally it will be required that the output should be directly proportional to the rate of change of temperature, the constant of proportionality being the same at all temperatures. This latter requirement cannot be met exactly with the system described, but by making R_3 and R_4 large compared with R_1 and R_2, an approximately constant relationship can be obtained.

Typical values used are $R_1 = R_2 = 4{\cdot}25 + 0{\cdot}0109\ T$ ohms, where T is the temperature in degrees centigrade, and $R_3 = R_4 = 100$ ohms. Using these values and a load resistance R_L of 75 ohms, the output from the bridge, for a rate of temperature change of 1°C per min, is reduced by 18% for a change in the measured temperature from 0°C to 500°C. The relationship between output and rate of change of temperature can be made more nearly constant by further increasing the resistances R_3 and R_4, but this necessarily reduces the sensitivity of the system.

. . . to PRESSURE

Digital output from manometer

The mercury manometer has long been accepted as a standard for the testing and calibration, over an appropriate pressure range, of measuring devices for absolute or differential pressure. Used as a measuring device itself, however, the manometer suffers from several shortcomings, one of which is the difficulty of obtaining rapid and accurate readings, particularly where these are required at a point remote from the instrument.

A new approach to the problem of obtaining direct readings from a mercury manometer—the 'servo manometer' designed by Bryans Aeroquipment Ltd.—uses an optical detecting head to locate the level of the mercury. This head travels on an accurate vertical lead screw running parallel to the mercury column. The signal from the photocell in the head is used to operate a servo-motor, which turns the lead screw in the appropriate direction to re-position the head. An accuracy of the order of 0·005 in. is claimed for this re-positioning system.

For local indication, a mechanical four- or five-digit counter is driven directly from the lead screw, while for remote indication the motion of the servo-motor is used to produce either analogue or digital output. The manometer can also be used as a controller, the position of the detecting head being set by hand, and the output signal performing a two-step control function. The glass tube limits permissible static pressure to 300 lb/in².

. . . to COMPUTATION

Logical-design teaching aid

G. H. STEARMAN, *College of Aeronautics, Cranfield*

The simple but flexible equipment described here was designed to provide a practical acquaintance with the principles of logical design. With its aid a large variety of circuits of the kind commonly found in digital computers and other digital systems may be constructed.

When teaching logical design, considerable use is made of symbolic logical expressions and the various means by which they may be simplified. Such expressions are quickly realized on this equipment and the equivalence of various forms emphasized so that it provides a valuable link between rather abstract theory and the actual hardware of computers.

The equipment consists of a base-board fitted with a number of pairs of sockets wired to a common power supply. Into each or any pair one of a variety of elements may be inserted; signal interconnexions between elements are then carried out by jumper leads terminated in miniature plugs. The various elements available are: 'input', giving a direct or complemented signal (a negative potential corresponds to a binary 1); 'and', having four diode-coupled inputs to an emitter follower; 'or', again with four inputs to an emitter follower; 'buffer/inverter', a two-stage transistor amplifier with an output from each stage; 'store', a bi-stable element with

Fig. 1 The main base-board set up for binary comparison. Each 'element' is built on its own individual base-board which plugs into the main board

direct and complemented outputs; and finally a pulse sequence unit comprising four push-buttons which may be used to simulate clock pulses. The circuits are all operated statically, allowing the use of a meter to check the states of various outputs and the manually-operated sequencing permits very slow step-by-step operation.

Circuits so far successfully constructed have included several forms of three-input adder, a counter, a shift register and a comparator to detect coincidence between two binary numbers. Multiplication and division are possible in principle, but rather more elements and base-boards would be required than have so far been constructed.

Pick-off

by 'UNCONTROLLED

I HAVE spent rather a large proportion of the past month looking at business computers and being blinded with science by those who profess to know where the ferrite matrix ends and the peripheral equipment begins. The *cognoscenti* tell me that it is all quite simple really and that with very little application on my part I too could begin to see the computer as the office manager's best friend. But I expect that I am not alone in my irrational fear of business computers, for their owners go to great lengths in their attempts to make the things attractive. They are

often installed in pleasant country houses, or mansions in the more well-to-do parts of cities, although whether this is to make the machines or their operators happy is an unanswered question. The operators are usually young ladies of the most charming aspect, presumably chosen to give the impression that if a pretty little girl can handle a computer then it should be child's play for a great big ugly engineer.

FROM what some of them have told me, the British delegates at the Ifac Congress in Moscow didn't have much of a holiday, and most of it was hard grind. The biggest difficulty was the language, but that was not the only barrier to enjoyment. Soviet delegates were not accommodated with the foreigners, and it was therefore very hard to start an acquaintance, let alone make friends with them. I was amused by the story of the opening Reception for delegates at the Scientists' Club in Moscow. The huge concourse gathered there at the appointed time, but nobody 'received' the guests. The absence of speechification, though surprising, might have been a kindly and understanding gesture; at least, it left people free to buy each other drinks and other refreshments from the side-tables. One of the delegates I know has had previous experience of Russian V.I.P. treatment, and tells vivid stories of how lavish and overpowering it can be. He thought, when he went to the opening reception, that the cool wind of change was blowing through the conference, and expected it to be equally frosty throughout. But no, the hosts unbent at the end, and everyone was invited to a slap-up affair at the magnificent Kremlin Palace. This time there was *free* food and drink—free in every sense—and there was also some first-class entertainment in the inimitable Russian manner.

THE Editor has let me see an instructive little note from R. J. A. Paul, who is one of the panel reporting the Ifac Congress elsewhere in this issue. Entitled 'Queueing Theory', Paul's little treatise provides an instructive survey of 'o.o.c.'. Visitors to the U.S.S.R. should know the rudiments of this theory because: 'the traveller on arrival at Moscow Airport is immediately subjected to some elementary topics. Passports are given up, forms are filled in, stamped and pocketed, and a random search is made for luggage. A *waiting* function is then applied, and a rumour spreads that it may be possible to retrieve your passport. Here is the first important concept, "the minimization of information processing": in other words, the synthesis of information by rumour. The enlightened traveller must now apply an interrogative function to maximize the known facts, which ultimately leads to receipt of passport. The waiting function of the complete process is not longer than a few hours, and eventually you embark on a coach for a hotel, the name of which is vaguely rumoured. On arrival at the hotel, the application of o.o.c. (optimization of organized chaos) begins in earnest. Queues are formed in a stationary random manner, and application of the interrogative function is essential to determine the ultimate purpose of each queue, when known. Here you get the best insight into o.o.c.; an ensemble of individuals has to be maximized in number and processed by the minimum number of receiving stations. The output for the latter is in the form of discrete samples of various coupons. The input is your passport and your return ticket to England. It is impossible to use the maximum principle here to obtain further information about the return of passport and ticket; you must become familiar with the important Russian phrase "Come back later". The interpretation of this is obtained by applying non-stationary statistical prediction theory, and logical analysis of sampled data given by other members of the ensemble. The waiting function for the complete process of reaching your hotel room is in the range of one to three hours.

'TRAVELLING between cities involves another good example of o.o.c. Before queueing for tickets, vouchers, and coupons (which will not be available until the last possible moment), a random search for passport is necessary. On receipt of the latter you must appreciate that the queueing theory is to become more involved than ever, in that the cross-correlation function may be zero and you may have to "come back later". This is a non-stationary process, but there is a certain probability that you will be asked to queue again in the early hours of the morning, just before the intended time of your departure. It is important to realize at this stage that signal reversion principles will not be effective, and you cannot decide not to go. Moreover, it is possible that a decision function will determine that certain members of the ensemble, who were not originally programmed for a visit, are now included in the signal flow. This process is irreversible, and all attempts to disprove this fact will end in failure. When all documents are in your possession, a periodic check function becomes necessary to ensure that at all times all documents are safely in your wallet.'

Paul concludes his note by wishing 'all travellers in the U.S.S.R.—*bon voyage*, infinite patience, and the optimum attitude of mind necessary for a pleasant visit.'

NEWS ROUND-UP

from the world of control

—— DATA PROCESSING ——

A profusion of computers

The past month provided so much information on digital computers (despite the title given to R. A. Brooker's account of the British Computer Society's recent Conference—*A lull in computers*, page 107) that little more than the most general report can be given. CONTROL saw the I.B.M. 1401, the A.E.I. 1010, and the near-complete Leo III, and received information on the embryo Ferranti Atlas and Elliott 503, to mention but a few.

I.B.M. 1401

This is strictly a high-speed office machine of—by I.B.M. standards—comparatively small size and low cost. The basic (£50,000) system consists of three units covering about 300 ft², which provide card reading at 800 card/min., processing at computer speeds, line printing at 600 line/min, and card punching at 250 card/min. Six magnetic-tape units, each giving a transfer rate of up to 62,500 ch/sec, can, however, be added. An unusual feature is the method of line printing with a chain of type faces operated by electrically-timed hammers. A high-speed 'skip' over unused sections of forms, is claimed to give it an output speed equivalent to that of a conventional printer operating at 4800 line/min.

Stretch for U.K.A.E.A.

Said to be the most powerful and versatile a.d.p. system in the world, an I.B.M. Stretch computer has been ordered by the Atomic Energy Authority. Capable of over 10^6 operations/sec and completing 10^{11} arithmetic operations a day, the solid-state machine for the U.K.A.E.A. will have random-access disk storage, six magnetic-core stores, and a 'vast' magnetic-tape backing store.

A.E.I.'s Computer Centre

CONTROL visited A.E.I.'s new Computer Centre at Sale, Cheshire, during July, to see the A.E.I. 1010 data processing system. This 'the latest and most modern devised so far . . . is the fastest now available in the world.' Completely transistorized, the machine incorporates a time-sharing system, known as the data-scanning equipment, which enables it to handle data at over 500,000 ch/sec. Data scanning enables up to 32 peripheral units to operate simultaneously. A system of parallel programming keeps idle-time to a minimum. From an example given, it appears that running two jobs in parallel takes only 5% longer than the time necessary for the larger of the two jobs run singly, and still leaves 28% of the total machine time available for a third, or even a fourth, job.

Fitted with junction transistors on printed boards throughout, the A.E.I. 1010 is comparatively small. The basic computing unit, including working store and control desk, occupies a floor space of 6 ft 6 in. by 2 ft 5½ in.

Leo III nears completion

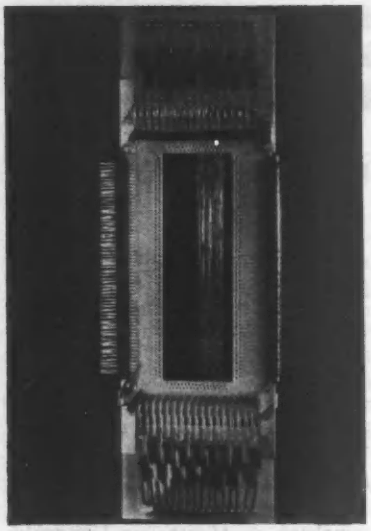
Leo Computers' transistorized Leo III, which CONTROL saw recently, has now reached the prototype stage. The first production model should be in operation by mid-1961. Understood to incorporate every major advance in a.d.p. techniques, Leo III provides: a large directly addressable quick-access magnetic-core store with automatic checking—one or more units, each of which will hold 4096 44-bit words, the access time being 7 μsec and a complete cycle 14 μsec; operation in decimal or any other notation; microprogramming by which a single program instruction can initiate a complex operation of the type entailing numerous steps—an idea originating with M. V. Wilkes, CONTROL's Consultant on computers and data processing; multiple input and output units operating simultaneously; time-sharing to give parallel program operation.

Atlas complete in 1961–62

The Ferranti Atlas, which should be completed at Manchester University by the turn of the year 1961–62, will be one of the world's fastest and most powerful computers, comparably only with the I.B.M. Stretch—see above—but, at £1m–£3m, roughly two-thirds the price.

The project stems from technical advances made at Manchester University, including a fast-carry adder and a rapid-access fixed store. The normal computing store will be a form of ferrite-core store employing two cores per bit. Each section of 4096 words will operate independently with a cycle time of 2 μsec; thus, by using several sections, a mean access rate of over 1 Mc/s is achieved (consecutive addresses appear in different sections). The average time to extract and execute a complete, single-address, floating-point addition instruction is expected to be 1·1 μsec, but this time will depend on the amount of overlap with adjacent operations. The effective speed of multiplication is such

The A.E.I. 1010 data processing system, claimed to be the fastest now available in the world, employs transistors on printed boards, so reducing its floor-space requirements to 6 ft 6 in. by 2 ft 5½ in.



A magnetic-core plane for micro-program control in Leo III

that, for example, summing a polynomial will take from 5 to 7 μsec per term.

The Elliott 503

Having developed transistor circuitry with a switching time of 5 mμsec—the circuit is understood to stem from work at the University of Illinois at the behest of the U.S. Atomic Energy Commission—Elliott Brothers have incorporated these high-speed switching techniques in their 503 computer. The development work for the 503 was done on a one-off job, the Elliott 502, and the 503 is now at the engineering stage and should be in operation before mid-1961. The machine is intended for the biggest jobs in scientific computation, using floating- or fixed-point arithmetic.

The 503 is designed for priority processing to enable more than one program to run at a time. It has a large ferrite-core store with a cycle time of 4 μsec, backed by magnetic-tape units, and output speeds up to 1800 ch/sec are possible. The arithmetic unit performs over two million operations a second. Typical operation times are: fixed-point addition, 8 μsec; floating-point addition. 8–15 μsec; floating-point multiplication, 15–25 μsec.

BUSINESS

Telephones and take-overs

Both the telephone manufacturers and the Post Office have been presented in a rather bad light by the national lay press during the past month, and many rather unfair, and indeed foolish, criticisms of their conduct have been made. This all stemmed from Pye's offer to purchase the Telephone Manufacturing Co.—Temco—a supplier to the Post Office along with A.E.I., Automatic Telephone and Electric, Ericsson Telephones, G.E.C., Marconi's Wireless, Plessey and Standard Telephones.

The latter companies—the 'consortium'—immediately made a counter offer which, peculiarly enough, was rather less than Pye's. That sparked off a verbal battle in press and Parliament: dark references were made to monopolies and 'rings', the foreign connexions of two members of the consortium were stressed, the cost and general standard of the telephone service in this country were compared unfavourably with those elsewhere, and the general merits of transfusing new blood from a dynamic young company into a stuffy old-fashioned set-up strongly advocated.

The consortium fought back rather feebly. The British telephone network, they said, was based on standard equipment; the Post Office liked the present arrangement, and, in any case, was quite capable of protecting its own interests. Furthermore, there was already much unused capacity in the industry. Far from being conservative in outlook, it had pioneered the development of world communication systems, and exported at least £25m of equipment a year—40% of their output.

Naturally enough, Pye, having offered more than the consortium for Temco shares, won the battle. However, Temco itself is subject to the same restrictive agreements which C. O. Stanley, Pye's chairman, finds so repugnant, and it is unlikely that their will be any lowering of costs to the consumer until the agreements are reviewed in 1962—if ever.

T.R.W. and the Common Market

Compagnie Européenne d'Automatisme Electronique has been formed in Paris by the following three firms: Thompson Ramo Wooldridge Inc. (T.R.W.), the U.S. industrial digital control computer firm; Compagnie Générale de Télégraphie Sans Fil (C.S.F.), the French electronics organization; and the Intertechnique Co., the French aircraft, industrial and nuclear electronics subsidiary of Générale Aéronautique Marcel Dassault. T.R.W.'s intention is to sell the RW-300 digital control computer in the European Common Market through the new firm. Indeed, C.E.A.E. is part of T.R.W.'s International Division and Intertechnique was formerly a licensee of T.R.W.

E.M.I.-Saab agreement

Swedish Saab Aircraft Co. and E.M.I. Electronics having agreed on technical and commercial co-operation, the former will sell E.M.I. equipment throughout Sweden, Norway and Denmark, through Saab Electronics of Stockholm. Similarly, E.M.I. Electronics will market Saab products in the British Commonwealth and other countries.

Saab manufacture aircraft, vehicles and electronic equipment including digital and analogue computers, numerically-controlled machine tools, instruments and special components. The two companies will also exchange technical information and licences.

Elliott-Hallikainen agreement

Elliott-Automation have entered into an agreement with Hallikainen Instruments, U.S.A., under which a new Elliott subsidiary, Hallikainen Instruments Ltd, will exploit the automatic analytical control instruments developed by Shell Research at Emeryville, California. U.S. Hallikainen will supply the Americas and Japan, and the Elliott company will supply the rest of the world. The instruments involved are mainly for in-line process control by continuous measurement of viscosity, vapour pressure, distillation, specific gravity and colour.

PROCESS CONTROL

American on-line computers

At an informal July meeting of the S.I.T., Francis Semmere of Thomson Ramo Wooldridge, U.S.A. (deputizing for M. Phister, Jr), gave a refreshingly uninhibited talk on the on-line computer. Apparently T.R.W. have done a number of on-line jobs.

Semmere said that you had to know a good deal about the plant before you could start. His company's approach was to do a preparatory study, usually involving eight to ten man-months of work. He admitted that much improvement was often possible merely from the findings of the study, but maintained that, on a complex plant, the computer would always give further improvement.

Questions at the meeting met with ready, and often amusing, answers. On the manpower question, Semmere said that computers did not reduce manpower, but they 'enabled manpower to be freed for more important duties.' Asked if there was any likelihood of conventional controllers being omitted from the loop, he replied that he did not think so; although the computer might be more reliable than an individual controller, the probability that

the computer would fail was nevertheless very much greater than the probability that all the controllers would fail simultaneously.

Although the talk and discussion on this occasion were of a rather general nature, Semmere infused more vitality into the proceedings than is customary in the sombre lecture hall at Manson House.

FUEL

Gas-meter diaphragms on test

Anticipating changes in the composition of British domestic gas, the Metropolitan Leather Company has built a new testing and research laboratory for gas-meter diaphragms. Metropolitan Leather—now metropolitan in name only, being situated at Great Harwood in Lancashire—is part of the Parkinson Cowan Group.

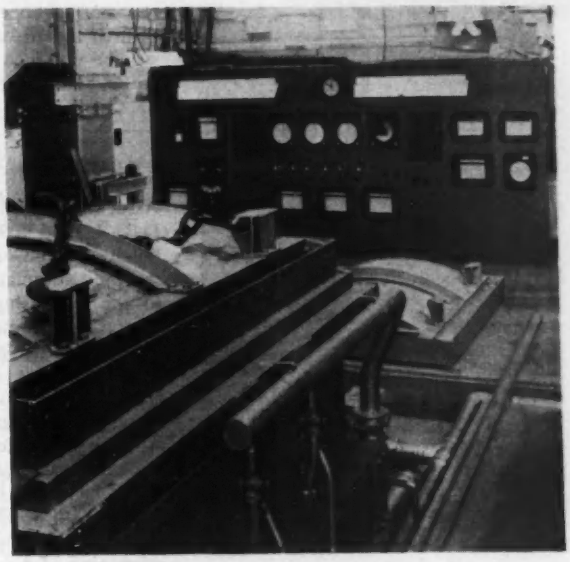
The new laboratory is carrying out controlled tests of relatively large numbers of diaphragms on a statistical basis, and conducting research into new materials. The traditional material is a semi-chrome tanned leather originating from East Indian sheep—known, we understand, as 'Persians' to the trade. This leather must be soaked in oil to render it impervious to gas, and it is important that the dressing should remain in the diaphragm during its working life.

The need for research of this kind, before changes are made in British gas, became apparent from recent American experience. The U.S. gas undertakings, in changing over to natural gas from gas made from coal, found that the leather was shrinking and cracking. By suitable advance research, Metropolitan Leather hope to avoid difficulties of this kind. In addition to tests on different types of leather diaphragm, various synthetic materials are being investigated. So far, no universally applicable substitute for leather has been found.

METALS

Bisra's new forge

A fully-instrumented experimental forge furnace completed last month in the Energy Section of The British Iron and Steel Research Association, will be used to investigate the thermal efficiencies of batch-heating processes. Its material of construction can be varied, as can the heating schedule, type of fuel and furnace load, re-circulation and waste heat recovery techniques.



Bisra's experimental forge is instrumented with a temperature programmer, combustion-air controller, oil- and gas-flow controllers, multi-point furnace temperature recorders with digitizing equipment, and a furnace - pressure controller

Temperature and flow

The complete heat balances at intervals throughout the heating cycles may be calculated. The furnace's temperature is measured with platinum/platinum-rhodium thermocouples, and is indicated and recorded on a Honeywell Electronik recorder-controller. The output from a pneumatic controller, within this instrument, is applied to the set points of the gas-, air- and oil-flow controllers. Oil flow is measured by a transmitting Rotameter and controlled by a diaphragm valve; gas and air flows are measured by orifice plates and the pressure drop transmitted by a differential converter to flow controllers which operate butterfly valves. The primary temperature controller is programmed to give the required heating schedules, the desired preset fuel-air ratio being automatically maintained by the secondary flow controllers.

There are over eighty thermocouples in the furnace walls and twelve within the three-ton ingot. These, together with further thermocouples in the furnace chamber, flues, air ducts, recuperator and stack, will be used to calculate the distribution of heat during operation. All these thermocouple outputs are recorded on four Honeywell twelve-point strip-chart recorders. A digitizing system is applied to two of the temperature recorders so that the bulk of the information may be recorded on punched tape for direct calculation with a Pegasus computer.

In order to minimize the leakage of cold air into the furnace chamber, a pneumatic butterfly valve is fitted in the stack and the pressure is held close to a set-point with a Honeywell pressure controller; it is recorded continuously on an Evershed and Vignoles electric pressure-recorder.

Gas analysis

The flue gases are continuously analysed. A Cambridge katharometer with a Honeywell strip-chart recorder and an Infra Red Development Co. infra-red analyser, are used to estimate carbon dioxide, whilst a Kent paramagnetic analyser measures the oxygen content of the flue gases.

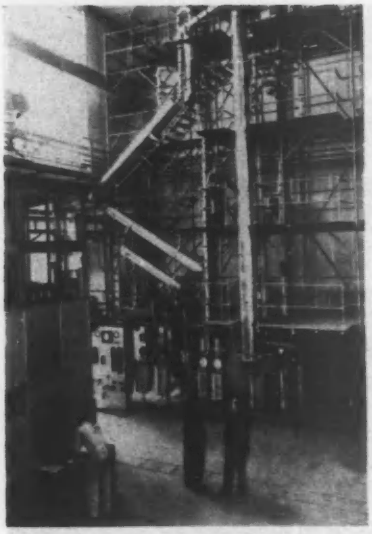
RESEARCH

Visit to Warren Spring

The Warren Spring Laboratory (Stevenage) of the D.S.I.R. had its first open day recently, having been in operation for just over a year. Being a successor to the now defunct Fuel Research Station, the new laboratory has inherited a certain amount of equipment and senior staff. This may well account for the impression it gives to the visitor of being well-established, in spite of its comparative youth.

One of the main functions of the Laboratory is to perform pilot-scale plant investigations. In this connexion CONTROL was interested to see a de Havilland Anatrol computer waiting to be programmed for use as an optimizing controller on a twelve-plate distillation column.

Development of the Fischer-Tropsch process for synthesizing fuels is being carried out on a number of pilot plants. On the largest of these plants (see accompanying illustration, reproduced by permission of H.M.S.O.) the temperature of the reactor is con-



Pilot-scale Fischer-Tropsch fuel synthesis plant at Warren Spring

trolled by varying the working pressure in the re-circulating cooling water system. The reaction being exothermic, the water jacket is effectively a small boiler blowing-off at the pressure corresponding to the required temperature. A further interesting point on the reactor column is the nuclear level-detector. This detector is driven up and down the column by a hand-controlled servo system. It is claimed that readings taken below the fluid surface—which, effectively, are indications of density—can be used to give information about the state of the reaction.

——NUCLEAR ENERGY——

Solartron control for I.C.S.E.

The U.K.A.E.A.'s intermediate-current stability experiment for controlled thermo-nuclear research at Culham, near Oxford, will have instrumentation and control apparatus by Solartron. Their responsibilities include manufacturing such control-room apparatus as voltage and current measuring and recording equipment of high accuracy and response speed. Gresham-Lion Electronics are also involved.

Temperatures at Trawsfynydd

Temperature-data handling equipment by Blackburn Electronics is to be installed in the C.E.G.B.'s Trawsfynydd nuclear power station being built by Atomic Power Constructions.

The installation will continuously scan some 670 temperatures in the reactor, covering the fuel elements, coolant and ancillary circuits. Each temperature will be checked every seventy seconds for departure from the normal operating levels, and a printed record of all the temperatures will be provided at intervals, together with a note of the time of the reading.

——STEEL——

A.E.I. link with Davy-United

Associated Electrical Industries and Davy-United have formed a jointly-financed Steelworks Automation Unit to apply automatic control techniques to the processing both of steel and of non-ferrous metals. CONTROL understands that the problems involved in full automation in the steel industry are considered to be too complex for a single organization to deal with. A.E.I. has therefore allied with Davy-United to establish this combined unit, which has been specifically organized to deal with everything from the stage of the initial design study to the commissioning of a fully operational production system in a plant. Such projects will include the combination of advanced servo-controls with computers to ensure the optimum performance of rolling mils and associated plant.

——MOTOR CARS——

Windshield projection for Bluebird

Among the many Smiths' instruments on Donald Campbell's new land-speed-record contender, Bluebird, is a combined accelerometer and speedometer whose indications appear continuously, as if projected on the track surface 100 yards ahead of the car. Known as a collimated instrument display, it has been produced by Kelvin Hughes.

Both the speedometer and accelerometer, which are in the same casing, are without pointers, and have dials which move against a fixed datum line.

Looking through the windshield the driver sees a vertical line (the datum line—which also acts as an aiming point for the driver to steer by) with two semi-circular dials one above the other. The top dial is calibrated in mile/hour, and the speed of the car is represented by the figure showing against the fixed vertical line. The lower dial shows the rate of acceleration in the same way. The driver does not need to move his eyes, or to change their focus.

The system operates by placing the instruments at the focus of a collimating lens and reflecting the parallel beam of light from an interference filter behind the windscreen.

The interference filter reflects a narrow wave-band in the middle of the visible spectrum, and transmits the remainder. It is mounted behind the windscreen, and through it the driver sees the outside world only slightly changed in brightness and colour, with the images of the two instrument dials in the centre of his field of vision. The lighting of the instrument dials is such that the maximum energy is at the wave-length corresponding to the peak reflexion of the 'trichroic reflector'. By means of this separation of the colour of the instrument dials from that of the light coming from outside the cockpit, the instrument markings can be discerned.

There are two categories of instrumentation in Bluebird—'cockpit' and 'research and warning'. Ten instruments and a number of warning indicators in the cockpit give the driver his essential operational information. The second category of instrumentation is used to provide information at base through a radio-telemetry system. The research and warning instrumentation provides operational information (and therefore to some extent duplicates the information available to the driver from his cockpit instruments) to provide a continuous record of each run at base, and also acts as an insurance lest the driver fails to notice, say, a drop in gear-box oil pressure. Furthermore it provides data on the behaviour of the car at high speed.

IN BRIEF

Solartron Laboratory Instruments has partially removed to Cox Lane, Chessington, Surrey; telephone Lower Hook 2150.

Lloyds Bank are to install three I.B.M.305 Ramac digital computers in their Pall Mall branch for processing customers' accounts.

Transatlantic telephone cable, TAT3, costing £12m should be operational in 1963, following an agreement between the Post Office and American Telephone & Telegraph.

1961 National Census data are to be processed by the Royal Army Pay Corps' I.B.M.705 computer.

Data processing on a commercial basis is available from de Havilland Propellers, Stevenage.

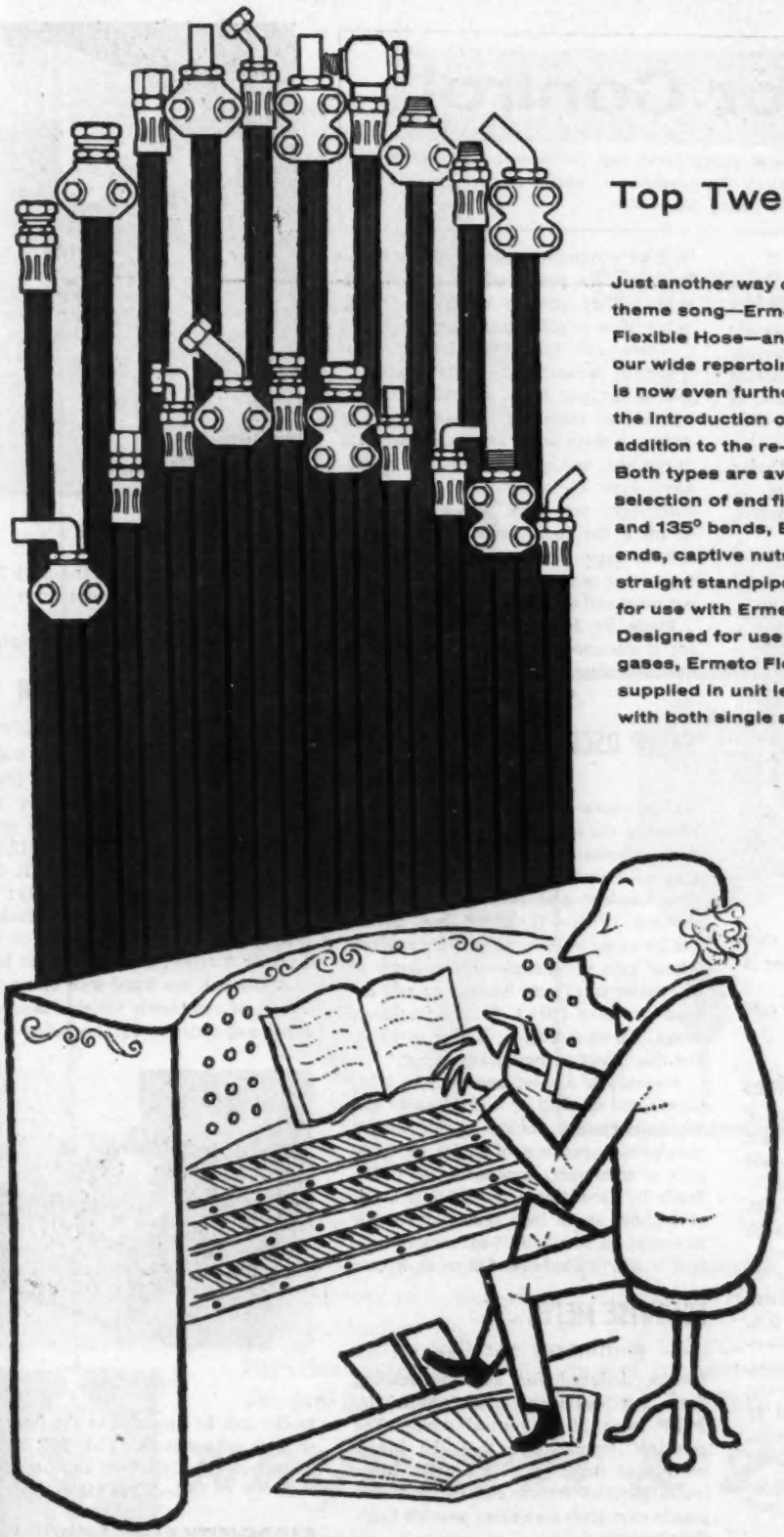
The I.E.E.'s Goldup Prize has been established for the best Higher National Certificate student who takes electronics or telecommunications subjects in his final examination.

Rumanian rubber tyre plant: Hunt and Mitton have received a £50,000 order for automatic and manual valving controlling steam, air, water and vacuum services to the Shaw McNeil Bag-o-Matic tyre vulcanizing presses.

Mininture crimped connectors by the Deutsch Co., U.S.A., are available from Smart & Brown (Machine Tools) Ltd., the sole U.K. licencees.

Consulting services in servo-electronics, analogue computation, automatic test gear and instrumentation are now available from Electronic Control Engineering Ltd., of Haywards Heath.

Malkara anti-tank wire-controlled guided weapon of the Australian Department of Supply will be handled throughout the world (the U.S.A. excepted) by Fairey Engineering.



Top Twenty?

Just another way of presenting our favourite theme song—Ermeto High Pressure Flexible Hose—and reminding you that our wide repertoire of endings (all happy) is now even further augmented by the introduction of pre-swaged ends in addition to the re-usable twin saddle type. Both types are available with a wide selection of end fittings, including 90° and 135° bends, BSP male and female ends, captive nuts, in addition to the straight standpipe end which is suitable for use with Ermeto pipe fittings. Designed for use with most liquids and gases, Ermeto Flexible Hoses can be supplied in unit lengths of up to 60 feet, with both single and double wire braiding.

ERMETO

BRITISH ERMETO CORPORATION LTD

HARGRAVE ROAD · MAIDENHEAD · BERKS · TELEPHONE: MAIDENHEAD 8100

A member of the ALENCO Group of Companies

Circle No 84 on reply card for further details

New for Control

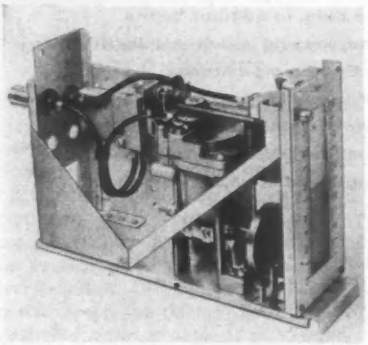
A monthly review of system components and instruments; for further information on any item, circle the appropriate number on the reply card facing page 146

EDGEWISE INDICATOR

pneumatically operated

This instrument indicates a pneumatic signal by means of a roller-blind moving against a 4-in. scale, which is calibrated on either side of the blind aperture. It may be fitted with two alarm switches, either electric or pneumatic.

The 110K indicator, made by Taylor Controls, fits a panel cut-out 6¼ in. × 2¾ in. The roller-blind drive and Servo-



Rapid indication

matic blind-motor are mounted on a slide which plugs into a manifold mounted in the back of the case.

Circle **No 523** on reply card

SERVO-COMPONENTS

international frame-sizes

Three additions to an existing range of servo-components include a size-15 a.c. motor-tachogenerator, a size-15 split-field d.c. motor, and a size-08 a.c. motor.

The tachogenerator has a 2-phase, 400-c/s motor, and an output of 3·0 V/(1000 rev/min). Linearity is given as ± 0·5%. The d.c. motor has a stalled torque of 160 gm cm at maximum excitation, and a maximum armature-current of 1·0 A. Field current and resistance are 40–0–40 mA and 400 Ω/winding respectively. The a.c. motor is 26-V, 2-phase, 400-c/s, and has a minimum stalled-torque of 21 gm cm. No-load speed is 6200 rev/min. These components are available from Vactric Control Equipment.

Circle **No 524** on reply card

SIMPLE SCANNERS

for process variables

These units compare incoming voltages against a preset alarm level; an alarm and an annunciator panel indicate points scanned and points which are off normal. They contain no moving parts other than a gold-plated uniselector.

There are three models available: Type B, accurate to ±40μV, scans 2 points/sec, and has a common red light and klaxon alarm for each set of twelve points; it stops when an off-normal point is reached, and must be re-started manually. Type C is similar, but has one alarm-light per point and a 'memory' to mark the fault while scanning continues; type D, accurate to ±10μV, scans at 7 points/sec, has one red light per point and a 'memory.'

Made by Honeywell, these scanners are constructed of drawer-units to fit a standard relay rack.

Circle **No 525** on reply card

SWEEP OSCILLATOR

using Wein bridge

An automatic sweep-oscillator, designed primarily for testing guided weapons, has two automatically - swept frequency ranges: 5 to 500 c/s, and 30 c/s to 3 kc/s. The standard unit sweeps according to the law $df/dt = (1/70)f^{4/3}$ but models can be made to order to provide any law whose rate of change of frequency at the extremes of any band does not exceed a ratio of 100 : 1. A third frequency range, 500 c/s to 20 kc/s, is also provided, but this is not automatically swept.

Accuracy of any set frequency is ± 2% (lower end of dial) or ± 5% (upper end of dial). Output voltage is 5 V into a minimum impedance of 20 kΩ or 0·5 V into a minimum impedance of 600 Ω. Made by Goodman's, the E502 is available either as an individual unit, or for mounting in standard 19-in. racks.

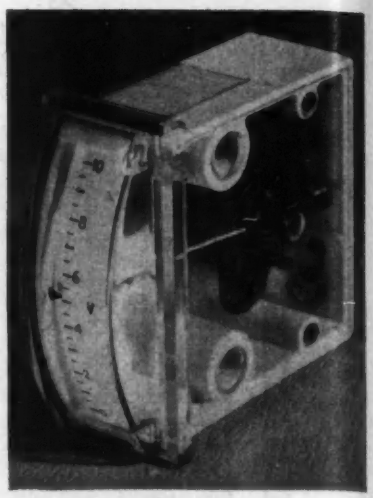
Circle **No 526** on reply card

EDGEWISE METER

eliminates parallax errors

Meters designed for accurate reading from any angle are manufactured by M.I.P. with 2½-in. vertical scales. The principal features are that the index, moving at the edge of the scale, eliminates parallax errors, and the use of a plastic case gives maximum possible light-distribution.

Movements for the Crystal range are available with the following maximum sensitivities for full-scale deflexion: moving-coil instruments, 10 mV or 20 μA



Easy to read

d.c., or (as a rectifier instrument) 3 V or 100 μA a.c.; moving iron instruments, 10 V or 5 mA a.c. or d.c.

Circle **No 527** on reply card

POTENTIOMETRIC RECORDER

small, accurate

Occupying panel-space 7¾ in. wide × 5½ in. high, a miniature recorder presents a continuous record on a 3-in. chart. Models are available with any one of six chart-speeds between ¼ and 12 in./h; chart life is one month at 1 in./h. There are six ranges of span-sensitivity: 1, 5, 10, 20, 50 or 100 mV for full-scale deflexion. Accuracy is given at ± 0·5% f.s.d. or ± 10 μV, whichever is the larger.

All models are fitted with either 10 or 20 mA of completely variable suppressed zero, and facilities for operating a con-

Easy access

troller can be provided in the form of a driven output-shaft. The MR 1035 is made by Firth Cleveland Instruments.

Circle **No 528** on reply card

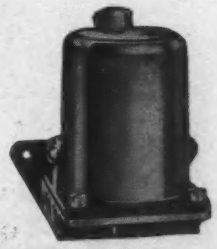
GAS-DENSITY-RATIO MONITOR

continuous sampling

An instrument by Griffin & George is designed to measure the composition of

TRANSMISSION CONTROL

"On plant" mercury-in-steel air-operated proportional temperature controller.
Publication No. R39



"On line" air-operated receiving controller. *Publication No. R31*

Mercury-in-steel air-operated temperature transmitter with Polyester resin glass-fibre cover, stainless steel base, stem and bulb. *Publication No. T39.*

High thermal response. Wide range of temperatures.
Standard output air pressure, 3-15 p.s.i. Small and compact.

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any two-component gas-stream. A gas-density balance is used to compare a stream of the reference gas with a stream of the two gases after mixing. The balance and associated equipment are enclosed in an air-circulated oven, the temperature of which is thermostatically controlled to within ±0·5% of any setting between ambient temperature and 150°C. This facility enables measurements to be made on non-standard gas-mixtures, such as water-vapour in a permanent gas, where the variable constituent would otherwise condense out of the mixture.

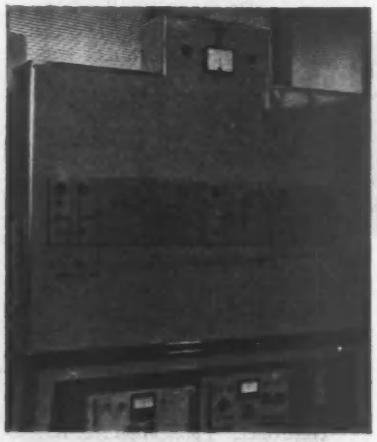
The recording unit incorporates a Honeywell potentiometric recorder, which may be housed up to 150 ft. away from the measuring unit.

Circle **No 529** on reply card

ANALOGUE COMPUTER

for education

Developed for universities and technical colleges, an analogue computer has a component accuracy of 1%. It is normally supplied for use with independent



Graphic display

power-packs and oscilloscope, as these are usually available in educational establishments.

As components for a particular problem are plugged into the computer base, a circuit diagram of the problem is shown automatically on the face of the instrument. Manufactured by Short Bros. and Harland.

Circle **No 530** on reply card

PORTABLE METER

measures coating-thickness

An instrument for measuring thickness of coating or plate operates by measuring the effect of the proximity of metals on a coil contained in a probe. Working on an eddy-current principle, with suitable calibration it will measure the thickness of non-conductive coatings on metal up to about 0·1 in., or the thick-

Meter adjusts to optimum angle

ness of coatings such as copper-plate on steel up to about 0·008 in. It may also be used to check the relative hardness of similar samples, by using samples of known hardness to set deflexion limits.

The Elcotector Mk. II, made by East Lancashire Chemicals uses transistors and printed circuitry, and works from self-contained batteries. Total weight in carrying-case is under 12 lb.

Circle **No 531** on reply card

TAPE UNIT

for digital computers

The maximum storage capacity of this unit is 160 million digits, on 3600 ft of tape 1 in. wide, and 0·0015 in. thick. Tape speed is normally 100 in/sec, but speeds from 50-150 in/sec can be provided to order. Channel capacity is 16 tracks.

A feature of this Epsylon unit is that start, stop, and reverse times are each 1·5 msec; this is achieved by the use of a reservoir on either side of the head, each of which holds about 15 ft of tape without tension. The quantity of tape in each reservoir is sensed photo-electrically, and an associated servo-system feeds in tape from the appropriate spool to keep this constant. It is claimed that

Fast reversing

the fast-wind facility enables a predetermined position to be selected to within 0·05 in. in 3·5 min. for whole tape-capacity.

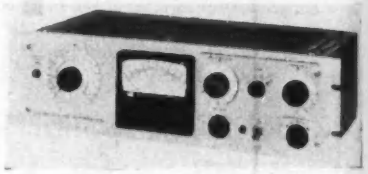
Circle **No 532** on reply card

MICRO-MICROAMMETER

fast speed of response

A unit designed for accurate measurement of very small currents has ranges (for full-scale deflexion) of 10^{-12}, 3×10^{-11}, 10^{-11}, etc., up to 10^{-8} A. Accuracy is ± 2% of f.s.d. from 10^{-8} to 10^{-8} A ranges, and ± 3% of f.s.d. for ranges from 3×10^{-9} to 10^{-12} A.

Read directly on two dials, zero suppression is available up to 100 × full scale. Response speed is less than 600 msec to 90% of final value at 10^{-12} A, provided external circuit capacity is 50 μF. Zero drift (after 30 min. warm-



Wide zero-suppression

up), is less than 2% of f.s.d. in 24 h on all ranges. Model 415, made by Keithley (U.S.A.), is available on special order for operation from 230-V, 50-c/s supplies.

Circle **No 533** on reply card

ALARM MONITOR

X or gamma radiation

For use in laboratories, or where background radiation is a possible hazard, this monitor consists of a halogen-quenched Geiger-Müller tube, a rate-meter, and an adjustable alarm circuit. This latter may be set to trip at any level between 0·05 and 10·0 mr/h. Any increase in radiation above the preset level causes a red lamp to be switched on. A double-trip version, having two independent alarm-circuits and an additional 'amber' warning light, is also available.

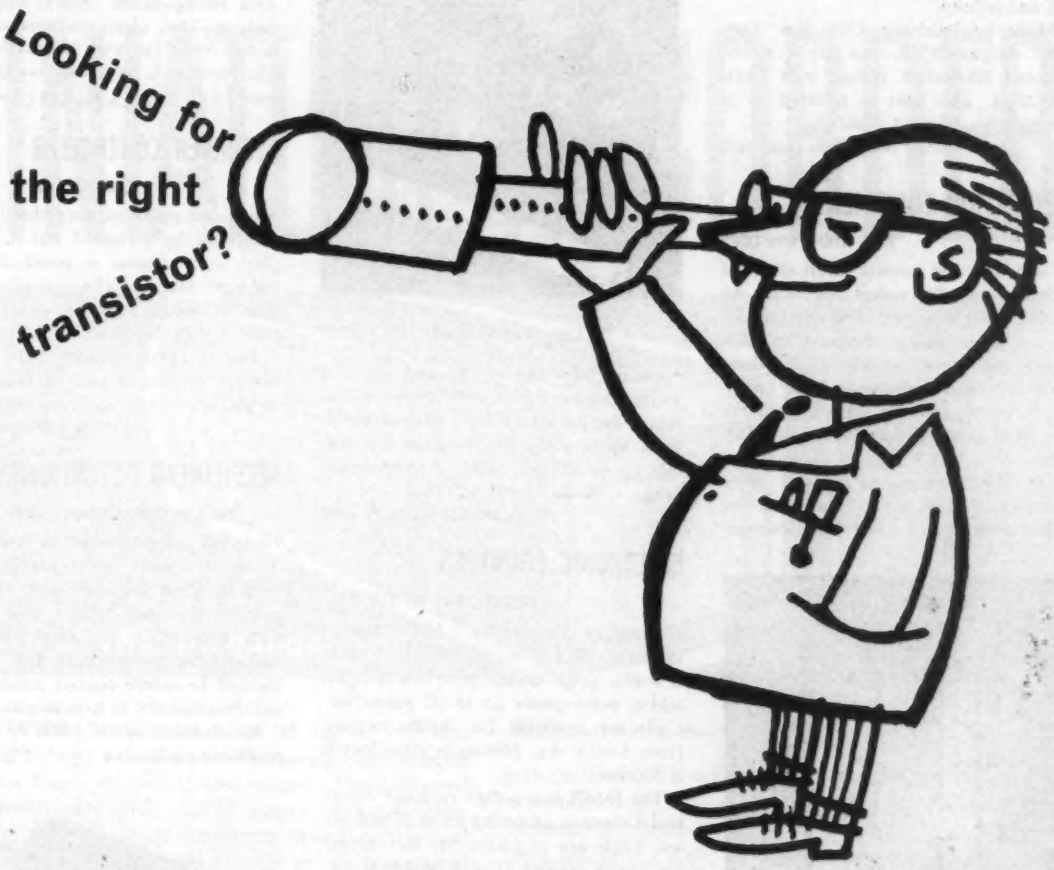
Made by Research and Control Instruments, the L.373 is available if desired with a 4-in. meter calibrated logarithmically over the range 0·01–10·0 mr/h. It will work from 105 to 115, 200 to 250-V, 40 to 150-c/s mains.

Circle **No 534** on reply card

VARIABLE-SPEED GEAR

constant torque

A mechanical variable-speed gear is designed to give constant torque over its entire reduction range. With a constant



If you are searching the horizon for something out of the ordinary in the way of transistors, it may not be as far away as you imagine. There's a whole new galaxy of Ediswan Mazda Industrial transistors, and the number is constantly increasing. We'll be pleased to send you detailed specifications of those that meet the requirements of the job you have in mind if you will send us details on your letterheading.

This could be it!

One of the important additions to our range is the XB121 germanium pnp alloy transistor with a **105 volt collector breakdown and punch through voltage rating** for high voltage low power switching and control applications.

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Circle No 86 on reply card for further details

input speed of 450 rev/min, the output may be reduced by any ratio between 9:1 and infinity.

Made by Fairbairn Ulro, the 'Contorq' weighs 385 lb, and has a totally enclosed lubrication system with visual indication. This unit is referred to in this month's *Ideas Applied*.

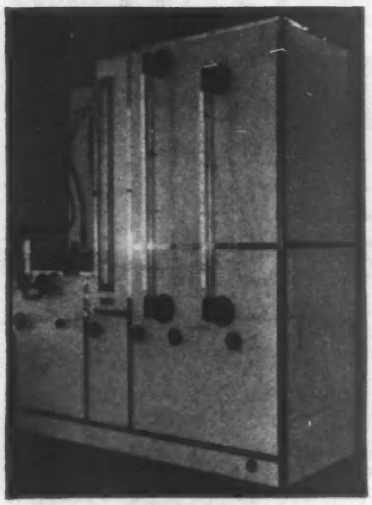
Circle **No 535** on reply card

CALIBRATION EQUIPMENT

for flowmeters

A unit for the on-site calibration of variable-area flowmeters operates by passing water at a controlled rate through the instrument being calibrated, and collecting the water in one of the three calibrated measuring vessels. The operation is timed, and the reading from the measuring vessel is taken from its sight-glass.

The three measuring vessels have capacities of 1, 8 and 60 gal., and are calibrated in $^1/_{10}$-, 1-, and 4-gal intervals



Wide flow-range

respectively. This Fischer and Porter unit will calibrate up to a maximum flow-rate of 60 gal/min water. Dimensions are 8 × 4 × 9 ft high.

Circle **No 536** on reply card

SUB-MINIATURE RELAYS

robust, sensitive

The Ugon range of relays, made in France, is now available in the U.K. from Leland Instruments. Weighing 0·2 oz, the relays are mounted in steel cases 25 mm long by 10 mm in diameter, and are hermetically sealed and pressure tested at below 20 mm of mercury.

The standard range of energizing coils covers 34 Ω to 14·5 kΩ; contacts are of two main types, one for current ratings

Less than King-size

between 0·15 and 0·5 A, and one for ratings below 0·15 A. The range covers relays designed to work under accelerations up to 150 *g*, at operating frequencies up to 800 c/s, within a temperature range — 70 to + 140°C.

Circle **No 537** on reply card

ELECTRONIC COUNTERS

read- or print-out

A range of counters by T.M.C. includes the EDZ12R and the DZ6R. The former is a slim single-decade print-out counter, taking pulse-speeds up to 10 pulses/sec. Coils are available for inputs ranging from 6–60 V d.c. Minimum pulse-length is 50 msec.

The DZ6R is a 6-digit read-out differential counter, accepting up to 25 pulses/sec. Coils are available for this model for inputs ranging from 6 to 240 V d.c. It has two acceptor circuits, and continuously reads the differences between the number of positive and negative pulses received. It is so designed that it reads correctly despite phase and frequency differences between positive and negative pulse-trains. Minimum and maximum pulse-lengths 20 and 50 msec respectively.

Circle **No 538** on reply card

THERMOMETER

measures wire temperature

If high drawing-speeds are used in wire mills, it is essential to monitor the temperature of the wire as it passes through the dies. An instrument has been designed by Addison Electric, in conjunction with Bisra, which will measure temperatures between 50 and 300°C over a speed range of 50-3000 ft/min.

Two pulleys of dissimilar metals, forming a thermocouple, are pressed against the wire, and the signal generated is passed from brushes on the pulleys to a meter having a response-time of 5-10 seconds. Accuracy of measurement is quoted as ±5%, and the wire to be measured may be 9-16 s.w.g. Calibration is not affected by phosphate coating, such as is used in drawing high-carbon steel, and the pulleys are fitted with spring-loaded paraffin-impregnated pads so that clean surfaces are maintained when the wire is heavily soaped. The device is portable, weighing just over 5 lb.

Circle **No 539** on reply card

RECORDER/CONTROLLER

three-term output

A two-unit electronic strip-chart recorder/controller by Evershed has a 4-in. display, and requires a panel cut-out of 144 mm². Standard chart-speeds are available to order, and the unit will work from 110 or 240 V a.c. mains supply.

The recorder may be used alone if desired; plug-in printed circuits are used to make for easy maintenance.

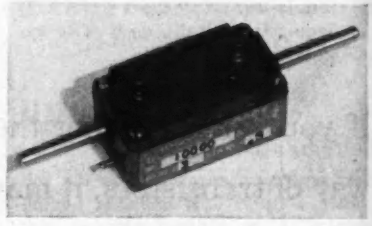
Circle **No 540** on reply card

RECTILINEAR POTENTIOMETERS

balanced-suspension wipers

Designed to overcome the problem of wiper separation under extreme conditions of shock and vibration, these units employ U-shaped wipers held in pressure equilibrium between commutator rod and resistive element. This system is claimed to reduce contact noise and signal discontinuity to a minimum.

Resistance range is 100 Ω to 10,000 Ω, resistance tolerance is ±3%; power



Shock resistant

rating and break-down voltage are 1·5 W and 1000 V respectively. Made by General Controls, weight is 1·2 oz, and life expectancy is given as 500,000 operations.

Circle **No 541** on reply card

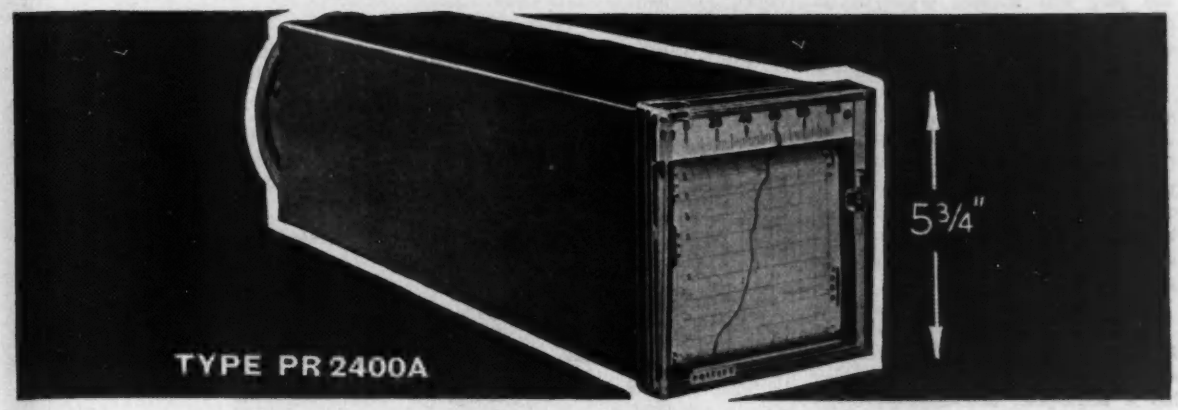
PNEUMATIC CONVERTER

square law to linear

The instrument converts a pneumatic signal proportional to the square of measured flow (e.g. from a differential transmitter and orifice-plate measuring system) to a linear pneumatic signal directly proportional to flow.

Made by Taylor, the Transcope Transverter is claimed to have an accuracy within ± ¼% of theoretical output between 4% and 100% of input, and within ± 1½% at 1% of input. Air supply needed is 20 lb/in² (25 lb/in² max.), and the response time for full scale deflexion is

PHILIPS
MINIATURE RECORDER



FEATURES Small panel space of 144 x 144 mm (approx. 5¾" x 5¾") · Reliable null-balancing potentiometer system · Easily interchangeable ranges · Transistorized plug-in amplifier with printed wiring · Unique chart-winding system · High indicating speed and critical damping · Scale calibration for mV or all conventional thermocouples · Completely mains operated.

RECORDING SECTION Strip chart, width 100 mm, length approx. 9 m. The chart is wound into an exchangeable casette. Visible length of 100 mm. After opening the door, the chart can be pulled out over a length of 80 cm. Chart returns automatically into the casette.

CHART-SPEED With built-in gear box 3 different speeds can be selected: 10, 20 and 60 mm/h. Can be supplied with electro-mechanical clutch so that by means of external switch, chart movement can be accelerated by a factor of 60.

Miniature mV-Recorder

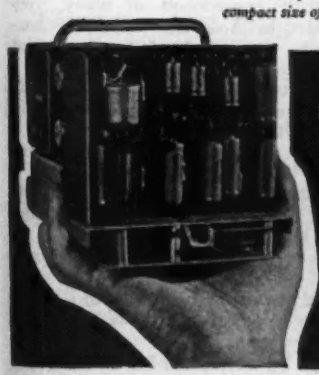
MINIMUM SPAN 5 mV · MAXIMUM SPAN 250 mV
ACCURACY 0·5%; the accuracy can be maintained after exchange of range box.
REPRODUCIBILITY 0·2% of span · SCALE LENGTH 100 mm.
STABILITY 10% mains variations have an influence of less than 0·1%
BALANCING SPEED Less than 1 sec. for full scale deflection; damping critically adjustable.

RECORDING With flexible capillary stylus supplied from sealed ink container mounted under measuring carriage. Line thickness approx. 0·3 mm.

CONSTRUCTION Sheet-metal case in grey hammertone with all plastic door. Front dimensions 144 x 144 mm; depth 510 mm; panel opening 138 x 138 mm. (5¾" x 5¾"—20"—5½" x 5½").

PRODUCT OF PHILIPS, EINDHOVEN, HOLLAND

This photograph shows the lighter weight and compact size of the plug-in transistorized amplifier.



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(RCL0009)

5 sec for a step change from 3–15 lb/in² with 50 ft of output tubing. Ambient temperature limits + 15°F to + 140°F. Designated model 208T.

Circle **No 542** on reply card

QUICK LOOKS

Printed-circuit frame for logic elements, made by Lloyd Instruments, will take up to twenty printed-circuit boards. The dimensions are made to suit a standard 19-in. rack. The cards slide in grooves, and plug into Mullard printed-circuit connectors mounted integrally in the main frame.

Circle **No 543** on reply card

Solenoid valve. A delayed-action solenoid valve, the V 4001 A, is available from Honeywell for controlling oil-supply to pressure-jet burners. It incorporates a delay mechanism which ensures that the burner fan reaches full speed before fuel is injected into the burner, ensuring complete combustion.

Circle **No 544** on reply card

Differential pressure control. Housed in a 6 in. diameter case, a unit by Tomey has a single-pole, double-throw, snap-action microswitch operated by a Bourdon tube. The unit is rated at 15 A 240 V a.c., maximum working pressure is 5000 lb/in².

Circle **No 545** on reply card

Digital computer. The Elliott 503, using new techniques, has a switching time of 5 μsec, and is claimed to be one of the fastest computers now available anywhere. Transistor printed-circuit boards are used for all logical, control, and storage functions.

Circle **No 546** on reply card

Transistors. Two Mesa high-speed switching transistors are available from A.E.I., designated XA 161 and XA 162. Minimum frequencies at which common emitter current-gain is unity are 25 and and 35 Mc/s respectively.

Circle **No 547** on reply card

Turbine flowmeters, designated Series EF 1030, are made by Firth Cleveland for rates of flow from 0·25 to 10,000 gal/min. Accuracy is given as ±0·5% over a flow-range of 10:1, and they may be used on line pressures up to 2000 lb/in². Temperature range is −200 to +160°C; high temperature units are available for use up to 500°C.

Circle **No 548** on reply card

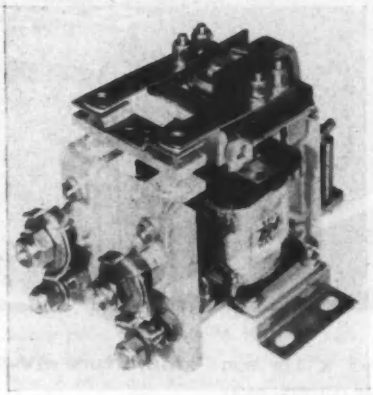
Beryllium monitor. A unit by Winston Electronics automatically checks the concentration of beryllium in the atmosphere, recording results at one-minute intervals. It is self-calibrating, and the normal cycle is 25 min. involving 5 calibration runs and 20 sample determinations.

Circle **No 549** on reply card

Sub-miniature motor. A timing motor by Haydon (U.S.A.) is 1⅜ in. in length and weighs 2 oz. The series 25100 works from a 400 c/s supply, and is rated at 115V, 20 mA. Torque rating is 0·01 oz in. at 3000 rev/min starting or running.

Circle **No 550** on reply card

Relay. This heavy duty relay, the C.15/C.65, has one normally-open contact rated up to 50A 250V a.c., and may also be fitted with a pair of auxiliary change-



over contacts rated 5A 250V a.c. Maximum coil-voltage is 270 V d.c. or 600 V a.c., and energizing speeds are 43 ms (d.c.) and 12 ms (a.c.). Manufactured by B. and R. Relays.

Circle **No 551** on reply card

Midget cylinders. A range of ¼-in. diameter, double-acting pneumatic cylinders is announced by Martonair. Designated type S.778, they are made in three stock lengths: 1-, 2-, and 4-in. Ports are tapped ⅛ in. B.S.P.

Circle **No 552** on reply card

Process timer. The Londex Imp timer is available with time ranges from 0-60 sec to 0-24 h. Models are either flush- or wall-mounting, and power-supply needed is 200-250 V a.c. Four change-over contacts are provided, each rated at 2A, 250 V a.c.

Circle **No 553** on reply card

Automatic calculator. An addition to the range made by Bulmer's is claimed to be the only desk-calculator in the world which extracts square-roots automatically. Its price is £660.

Circle **No 554** on reply card

Cold-cathode tubes by Elesta (Switzerland) are available from Britec. The range includes decade selector-tubes, and trigger and relay tubes for both a.c. and d.c. operation.

Circle **No 555** on reply card

INDUSTRIAL PUBLICATIONS

Level indicator. A one-page leaflet describes the 'Levelog' made by Thomas Industrial Automation.

Circle **No 556** on reply card

Furnace control. Instrumentation and automatic control for re-heating furnaces is discussed in leaflet 2023 from George Kent. Circle **No 557** on reply card

Weld controllers. Two capacitor-discharge weld-controllers are described in a leaflet from Hirst Electrical.

Circle **No 558** on reply card

Precision servo-components. Abridged technical data is to be found in a pamphlet from Vactric.

Circle **No 559** on reply card

Photomultiplier tubes by 20th Century Electronics are listed in leaflet PM.405.

Circle **No 560** on reply card

Low-voltage supplies and current stabilizers are listed in bulletin 60/6 from Joyce, Loebl.

Circle **No 561** on reply card

Servo-system. The ES 1A, designed for instruction and demonstration to students, is shown in a 4-page leaflet from Feedback. Circle **No 562** on reply card

Flame detector. Sensitive only to ultra-violet radiation, Honeywell's 'Purple Peeper' is shown in a colourful leaflet.

Circle **No 563** on reply card

Precision thermostats by Texas Instruments (U.S.A.) are illustrated in a 4-page booklet.

Circle **No 564** on reply card

Data transmission. The Strad system of automatic re-transmission is described in a booklet from S.T.C.

Circle **No 565** on reply card

Temperature regulators. Models ranging from 150 lb/in² at 400°F to 600 lb/in² at 600°F are listed in British Arca's catalogue No. 0126/60.

Circle **No 566** on reply card

Miniature components of many types are listed by Ardente in their 1960 catalogue. Circle **No 567** on reply card

Process control. Elements for an electronic control-system are described in leaflet EPC.1 from Fielden.

Circle **No 568** on reply card

Regulating units, air operated, are illustrated in Negretti and Zambra's booklet No. R30/RU.

Circle **No 569** on reply card

Printed circuits. A booklet from Bribond includes technical data as well as a general description.

Circle **No 570** on reply card

The AMPEX CP-100 is a compact, extended-frequency instrumentation tape recorder/reproducer. Tape transport, motor drive amplifier, heads, power converter, controls and all-transistorized plug-in record/reproduce electronics are contained in a single 13¼" x 19" x 33¼" mobile case. The CP-100 operates on 28-volt DC, with 48 to 400 cycle converters available for other power sources. Data is recorded by direct or FM carrier techniques on up to 14 analogue tracks. The CP-100 offers frequency response to 200 Kc at 60 ips or expanded recording time of 24 minutes for 100 Kc data at 30 ips on a standard 10½" reel. Transport tape speeds – 1⅞, 3¾, 7½, 15, 30 and 60 ips – and plug in frequency determining units and equalizers associated with tape speeds, may be quickly changed. The versatile and mobile CP-100 performs reliably over a temperature range of from −50° F to +160° F, up to an altitude of 10,000 feet, in relative humidities to 95%... and is designed to withstand shocks and vibrations encountered in rugged mobile testing applications. This recorder may also be rack mounted if desired. For complete details write Ampex Great Britain Limited, Arkwright Road, Reading, Berkshire, England. AMPEX

Book Reviews

Servo-mechanisms

Servomechanism Practice *by* **W. R. Ahrendt** *and* **C. J. Savant.** *McGraw-Hill Publishing Co. 1960. 566 pp. £4 17s.*

The subject matter of this book is mainly concerned with servo-mechanism components. Complete systems only occupy some seventy pages, but therein is contained a number of useful expressions, and although these are to be found in more detail in other books, they stand out by virtue of their very isolation.

The components dealt with include position-, rate- and acceleration-measuring instruments, modulators and demodulators, networks, amplifiers, servo-motors and gyroscopes. Each is given a theoretical treatment and the practical aspect is discussed. The treatment of acceleration is particularly good. Hydraulic and pneumatic systems are well described in thirty pages and there are two chapters, one on servo-mechanism manufacture and the other on testing. The title of the latter (*Test of Servomechanisms*) is somewhat misleading as the tests are mainly concerned with components. The whole is co-ordinated by a final short chapter on a typical (*sic*) servo-mechanism and its operation.

The book is very well produced: the diagrams and illustrations are good and the layout follows the logical sequence of a system. There are many useful practical hints and several tables of current component characteristics which, however, being American, lose some of their value for British readers. A number of tables, including a very useful one of conversion factors for all the usual quantities encountered in servo-mechanism practice, is appended. The factual data are good, but the physical explanations are not always as clear as they should be, in spite of unnecessary repetition in the same paragraph (p. 319). Also, such statements as 'practically instantaneous' response (p. 268) should not be made in a serious book, especially when followed by a table giving time constants up to 0·4 s (p. 271).

The book, can nevertheless, be recommended as a useful addition to the servo-mechanism engineer's library, but only as one complementary to more theoretical treatises and books devoted to complete system analysis. A bibliography of 53 tables is appended.

G. ASHDOWN

Systems

Control Systems Analysis and Synthesis *by* **John J. D'Azzo** *and* **Constantine H. Houpis.** *McGraw-Hill Publishing Co. 1960. 580 pp. £5 4s. 6d.*

Why was this book written? This is a question that many control engineers will ask when confronted with this book, bearing in mind the already large number of textbooks on the subject. The justification for a new textbook on control systems theory must surely be either that the book has original content or that it has an original manner of presentation. A book such as this, which is intended primarily for undergraduates, can hardly be expected to have much original content, so it is on the matter of presentation of material that this work must be judged.

Unfortunately, on reading through this volume one frequently gets the feeling of having read it before. Apart from some new examples here and there, much of the material and its presentation is little different from that readily available in previously published books. The authors may have achieved a new combination of topics in their book, but their originality of approach is not very evident. Apart from this, the book suffers in parts from loose statements and such doubtful philosophical pronouncements as, 'the art of automatic control systems . . . can be considered to act as a catalyst in ensuring the peace or destruction of the world'.

To be fair, however, the book probably attains the authors' objective of being a 'good textbook from the student's point of view'. For the student who wishes to learn about basic control-system ideas such as transfer functions, root locus methods, frequency response, logarithmic plots, stability, compensation methods; a.c. systems, use of analogue computers etc., this book is likely to be quite suitable. But the student who already possesses a good control-systems textbook will not learn much from this one.

R. J. KAVANAGH

Noise

Electrical Noise: Fundamentals and Physical Mechanism *by* **D. A. Bell.** *D. Van Nostrand Co. Ltd. 1960. 342 pp. £2 10s.*

On its dust cover, this book is described as 'a unified reference and source book on electrical noise . . . intended for research workers in electrical engineering and applied physics'. As a statement of aims, this description would be difficult to better. In attempting to produce a book of 336 pages that 'covers the whole field, including historical theory and controversy, in a complete guide to all that is known about the subject up to the present time', the author sets himself a prodigious task. His concise literary style and logical presentation makes him equal to this. An undergraduate coming to this subject for the first time, or the postgraduate embarking upon his first serious study of electrical noise, would require supplementary material. This is not a reflexion on the author's presentation, but rather it confirms the success with which he has achieved the declared aim. This is *not* an introductory student text, but is indeed a source of reference for the research worker.

To facilitate the choice of supplementary material the reader is presented with more than 400 carefully selected references, representing the combined contributions of over 250 research workers. If the same care had been expended in the preparation of a detailed subject index as was expended in the collection and selection of these, the value of the book as a work of reference would have been still further enhanced.

Any library serving the needs of electrical engineers and/or applied physicists which does not include this book on its shelves is guilty of an error of omission.

R. A. WOODROW

Literature Received

British Instruments Directory 1960. *United Science Press Ltd. 1960. 635 pp. £2 5s.* ★ 701

Association of Consulting Engineers, Report of the Council. *Association of Consulting Engineers. 1960. 111 pp.* ★ 702

Control Systems Engineering. *Edited by:* **William W. Seifert** *and* **Carl W. Steeg, Jr.** *McGraw Hill Publishing Co. 1960. 964 pp. £5 16s. 6d.* ★ 703

Hydraulic Oils. *Wakefield-Oil Industrial Oils Ltd. 1960. 74 pp.* ★ 704

D.C. to D.C. Transistorized Converters *by* **R. A. Holme.** *Standard Telephones and Cables Ltd. 1960. 46 pp.* ★ 705

Temperature Measurement and Control *by* **W. F. Coxon.** *Heywood & Co. Ltd. 1960. 314 pp. £3.* ★ 706

Graphical Symbols for Components of Servo-mechanisms, Part 1: Transductors and Magnetic Amplifiers. *B.S.3238: Part 1: 1960. British Standards Institution. 16 pp. 4s. 6d.* ★ 707

Photoconductivity of Solids *by* **Richard H. Bube.** *Chapman and Hall, London: John Wiley, New York. 1960. 461 pp. £5 18s.* ★ 708

Self-saturating Magnetic Amplifiers *by* **Gordon Lynn** *et al. McGraw Hill. 1960. 217 pp. £3 2s.* ★ 709

★ Circle the relevant number on the reader information card facing page 147 for further information.

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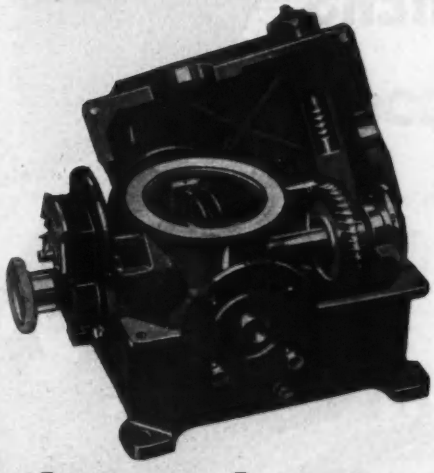
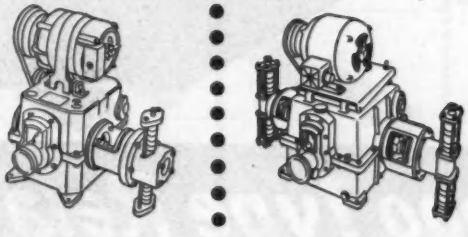
The gearbox



is the very heart of a metering pump



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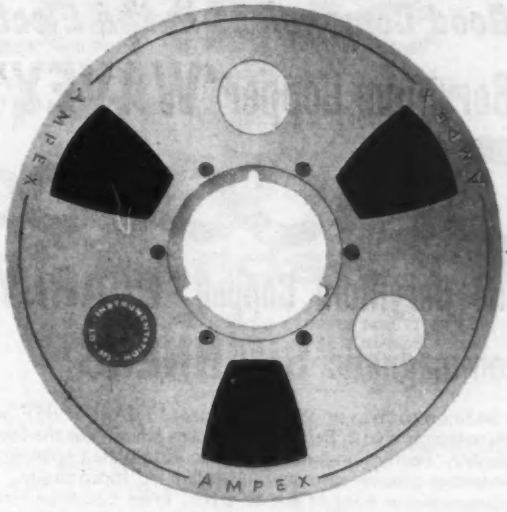

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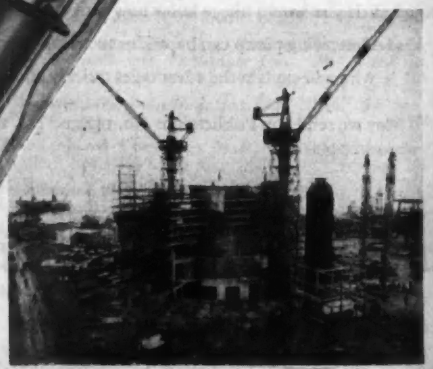

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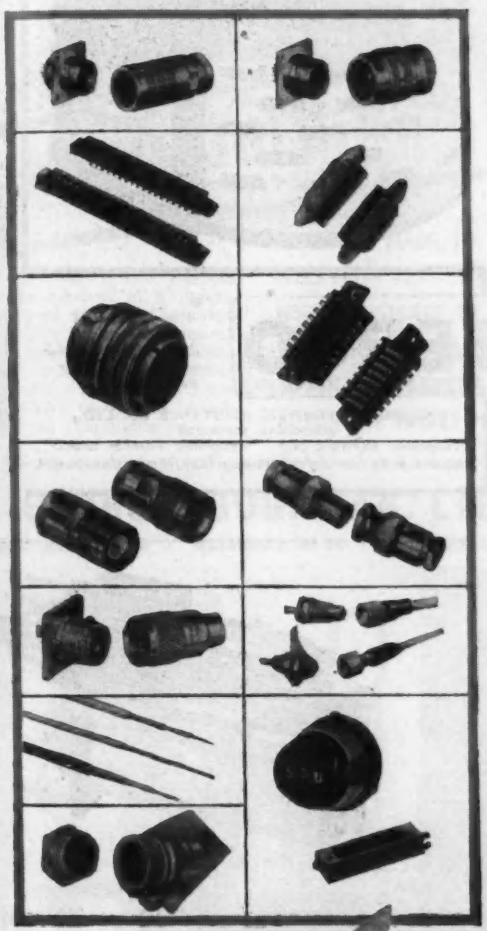

The ARC 52 Equipment installed in the "Lightning" (photo reproduced by courtesy of the English Electric Company Ltd.), the Vickers-Armstrong "Scimitar" and other military aircraft incorporates Amphenol 165 Series Connectors.

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- Rigidly constructed from 10 gauge formed steel sections and finished in silver grey hammered stoving enamel.
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- Price £38 . 10 . 0.
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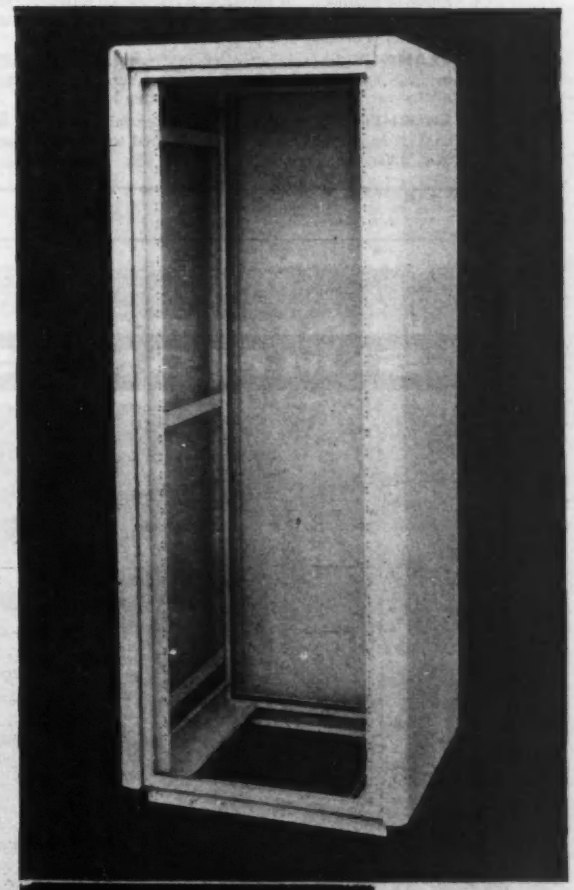

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. . . with universal fixing centres

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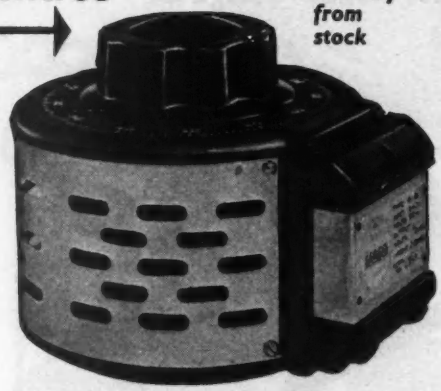

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- **CONSTRUCTION:** Toroidally wound auto-transformers, with tracks formed on one face of the windings.
- **CORE:** Wound from a continuous strip of low loss electrical steel in a similar manner to the well-known C core construction.
- **INSULATION:** Specially processed plastic mouldings ensure minimum shrinkage due to heat and continuous use, and prevent any possibility of the turns slackening.
- **WINDING:** Of high conductivity copper, insulated with a synthetic enamel of the polyvinal acetal-phenal formaldehyde resin type, giving good space factor, exceptionally high abrasion resistance and prolonged heating resistance.
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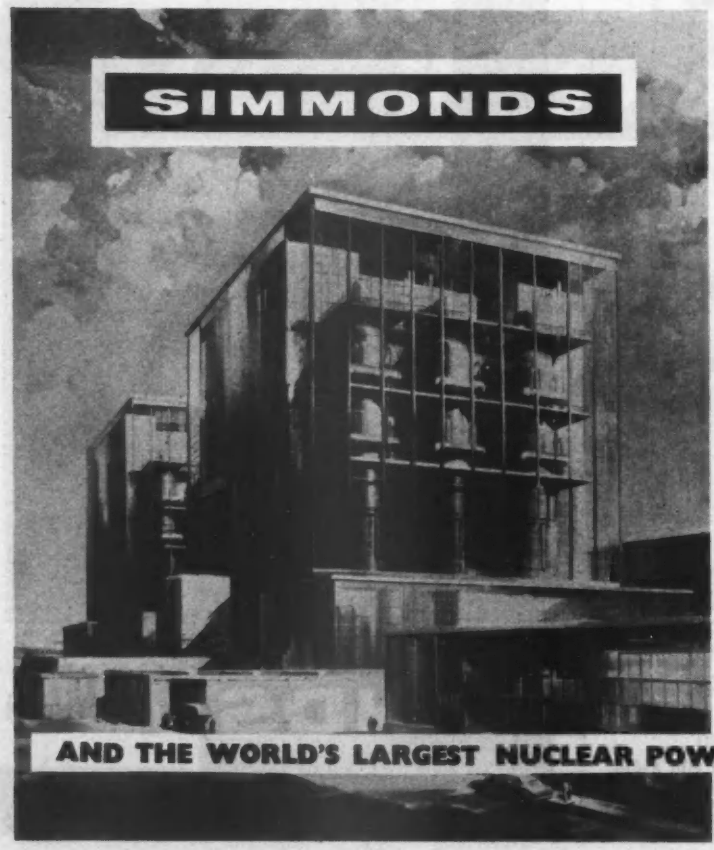

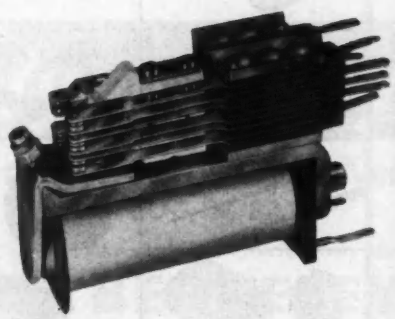

Over 10,000 Simmonds G.P.O. type 3000 relays have been ordered for this new station to the special requirements of The United Kingdom Atomic Energy Authority and the Central Electricity Generating Board. We are proud to be associated with English Electric and Marconi Instruments in this vast project and to be entrusted with this exacting work. Hinkley Point nuclear power station is being built by The English Electric, Babcock & Wilcox and Taylor Woodrow Atomic Power Group.

AND THE WORLD'S LARGEST NUCLEAR POWER STATION — HINKLEY POINT

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Telephone: Harrow 7797/9. Telegrams: Simrelay, Harrow.

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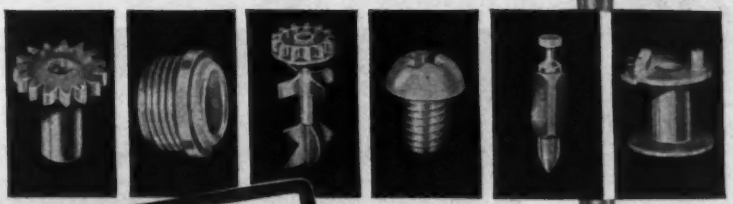
Precision Parts in *NYLON*

CUT COST OF ENGINEERING PRODUCTS



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PRECISION MADE TO YOUR SPECIFICATION
SIZES FROM NEXT-TO-NOTHING UP TO ½ oz.
HIGH RESISTANCE TO ABRASION
HIGH DIELECTRIC STRENGTH
TOUGH, SELF-LUBRICATING, etc.
AUTOMATIC INSERT MOULDING

★ *Send us one of your small assemblies for a 'quick quote' — it may surprise you!*

Thought about using

GG MINICASTS *

in Zinc Alloy?

There's nothing to touch GG MiniCasts for tiny metal parts — *cost less* because all machining, assembly, welding, scrap and tool costs are either reduced or eliminated. Send for free details today!

* *Diecasting made by new high speed automatic process. Supplied completely trimmed ready to use.*

GEORGE GOODMAN LTD

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DISPLACEMENT RANGE 1 to 136 c.f.m.

In the Food Processing, Brewing, Chemical and Paper Industries, also for pneumatic instrument control, it is essential that the air is free from oil in both droplet or vapour form. The W&J compressors use carbon rings and completely dry cylinders to achieve this purpose.

Manufactured now for several years they have proved themselves successful in many industries.

For further details please write requesting Leaflet Nos. 4, 20, and 28.

Illustrated is the twin cylinder model having a free air delivery of 50 c.f.m.

WILLIAMS & JAMES ENGINEERS LIMITED
GLOUCESTER · ENGLAND
TELEPHONE GLOUCESTER 24021-2-3 TELEGRAMS & CABLES COMPRESSOR GLOUCESTER

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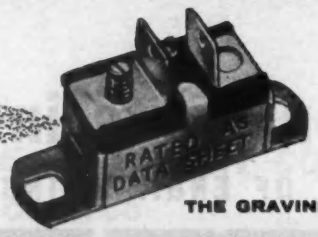
Pin-point Automatic Accuracy



THE GRAVINETTE

Write for Catalogue G. 100 Temperature Control Switches

THE GRAVINETTE

A miniature precision unit for Surface Mounting, to provide for optimum temperature control on applications where space is at a premium. The Gravinette is an adjustable unit and is offered in four versions :—

Type TCS 3150, normally closed, range—70°C to 100°C,
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Normal rating 1 amp. on 250v A.C., and 2 amps on 28v D.C.

CARTRIDGE TYPE SERIES 1000, TENSION OPERATED

These precision temperature control switches are designed primarily for use in heater blocks, heated plates and similar applications where excessive moisture or vapour is not present. Possessing the desirable features of the ideal thermostat, the Graviner Temperature Control Switch is of convenient size and shape, adjustable and resistant to vibration and shock, and easy to install.

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S SWITCHES

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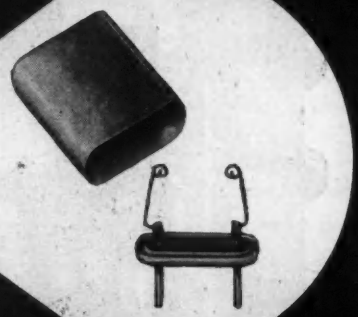

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AUSKUNFTSDIENST FÜR LESER

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Часто бывает трудно рекламирующим лицам давать все технические подробности своей продукции в рекламе. Если Вам понадобятся добавочные сведения, то просто отметьте соответствующие номера на карточке на противоположной стороне и отправьте в CONTROL

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在廣告上以有限的地方來解釋一些專門技術及它們的用途，的確是有受限制的困難。倘若欲要知道一些詳細的情形或特別項目的表格，就一張下表簡單的填寫的項目，同寄回一封普通信函至貴工程處即可。

読者サービス

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are chosen by the

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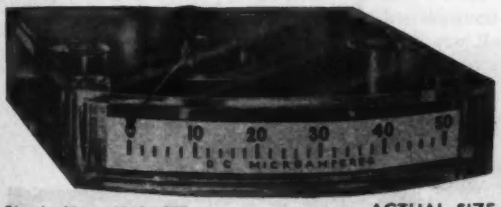
fitted in Comet Jet Airliners

FORTIPHONE TRANSFORMER DIVISION (DEPT. 3) 92 MIDDLESEX ST. LONDON E.1.

NEW Taylor METERS

NEW MINIATURE EDGEWISE METER



Edgewise Meter, Model 220 ACTUAL SIZE

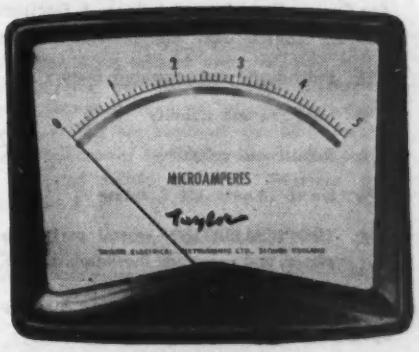
A new miniature Edgewise Meter occupying approximately one quarter panel area compared with meters having equivalent scale lengths. Transparent case provides shadowless readings and design of the moulding allows room for self contained circuitry and components. Our centre pole movement is incorporated, providing inherent magnetic shielding, allowing meters to be mounted in close proximity. Comparative readings can be obtained by mounting two Edgewise Meters next to each other.

★ MAXIMUM READABILITY
★ MINIMUM PANEL SPACE
★ LIGHT WEIGHT

NEW CONTEMPORARY METERS TAYLOR "VISTA" RANGE

A completely new range of modern style Panel Meters in 2"—6" mouldings incorporating our well established centre pole movement of extreme robustness. Cases available in various colours: sensitivities from 5 micro amps.
Very competitive prices.

★ OPEN SCALES
★ MODERN DESIGN
★ HIGH SENSITIVITY



We also manufacture a wide range of Electronic Equipment including: Valve Testers; Multi-range Meters; Oscilloscopes; Generators; Valve Volt Meters; Wobbulators; Audio Generators; Bridges, etc.

Prompt delivery: prototypes—7 days quantities—4 weeks

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TAYLOR ELECTRICAL INSTRUMENTS LIMITED
MONTROSE AVENUE, SLOUGH, BUCKS. Telephone: Slough 21381 Cables: Taylins, Slough
Members of the METAL INDUSTRIES Group of Companies

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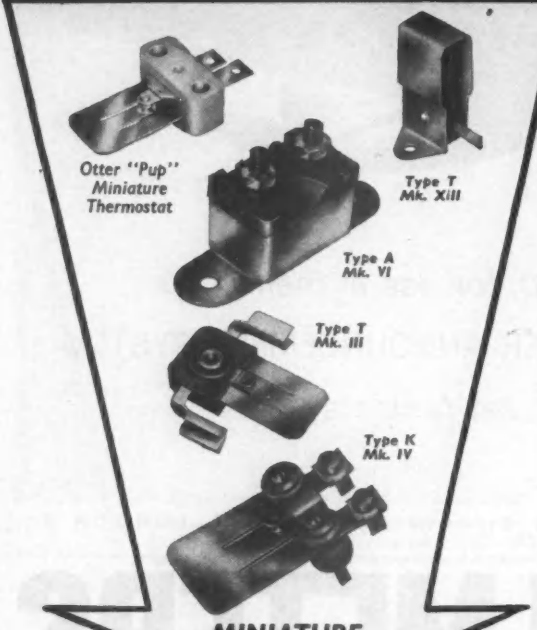
Otter REGD.

WORLD PATENTS INCLUDING PATENT NUMBERS 600055 622781 624905 657434 713443 749716 774911 782668 AND OTHERS ALSO OTHER PATENTS PENDING



SNAP ACTION
THERMOSTATS & SAFETY CUT OUTS

For Quartz Crystal control, Radar & Electronic Equipment Control Gear and Airborne Equipment

- ★ Individually and accurately factory set
- ★ Long life and stability
- ★ Robust and reliable
- ★ Up to 20 amp. 250 V. rating
- ★ TROPICALISATION—metal parts may be silver plated, and top grade insulation is used.

All Otter thermostats "Press their contacts together to open them with a SNAP!"

OTTER CONTROLS LIMITED
OTTERS OLE, BUXTON, DERBYSHIRE
Phone Buxton 650 (2 lines)

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Portable . . .

TYPE MC—I (MK.III)

CONDUCTIVITY MEASURING BRIDGE

The type MC-1 conductivity bridge is an invaluable aid to the water engineer in the laboratory or in the field, for the determination of water purity, where it may be depended upon for precise, accurate measurement and trouble free service.

The instrument is supplied complete with an ELECTRONIC SWITCHGEAR patented, non-glass conductivity measuring cell and all accessories, in a convenient hardwood carrying case. The development of low power consumption transistorised circuits, which operate from a small long life dry battery, has resulted in the production of a particularly compact and lightweight precision instrument.

Descriptive leaflet MC-1 available on request.

ELECTRONIC SWITCHGEAR
(LONDON) LTD.
LETCHWORTH · HERTS · TEL: 1853

ELECTROLYTIC CONDUCTIVITY MEASURING SETS, RECORDERS, CONTROLLERS AND CELLS · CONTROLS FOR LIQUID AND SOLID LEVELS · TIMING · PHOTO-ELECTRIC PACKAGING REGISTRATION · ETC

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Type LP 2

PENNY & GILES

MUDEFORD · CHRISTCHURCH · HANTS
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RECTILINEAR POTENTIOMETERS

FOR REMOTE INDICATION AND RECORDING OF DISPLACEMENT

STROKE LENGTHS
Up to 9 inch for Type LP 2
Up to 24 inch for Type LP 1

TWO RESISTANCE ELEMENTS

AMBIENT TEMPERATURES
Available for use in the following ranges
−50°C to + 85°C
−50°C to +150°C
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RESOLUTION of 0·001 inch can be achieved

WRITE FOR DATA SHEETS

Also manufacturers of potentiometers in size 11 and size 15 synchro mountings.
Single and multi-gang. Single and multi-turn.

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Simplified Control with NEUMO

AIR OPERATED PUMPS and MOTORS

Many industrial users are finding that control of liquid flow by means of a simple valve in the delivery line is all that is required when using Neumo positive displacement air operated pumps. This valve may be at any distance from the pump enabling operators to control pumps at distant points of delivery.
The system is reliable because no extra control gear is employed, the pump merely stalling by back pressure in the delivery line and recommencing delivery upon release of the pressure. The possibility of raising undue pressure in the line is avoided by automatic over-load devices in the pump which can be set to come into action at a predetermined pressure.
Pumps are made in a wide variety of materials to cope with all liquids. Neumo motors containing only two moving parts are a safe, reliable means of obtaining reciprocating motion and again may be stalled without damage.

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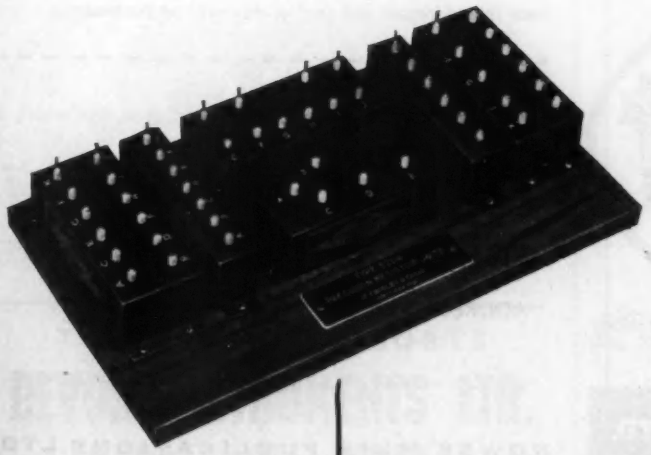
NEUMO LIMITED
South Coast Road, PEACEHAVEN, Sussex.
Telephone: Peacehaven 2115 & 3354.

Tinsley

PRECISION COMPONENT RESISTORS

with Resistance tolerance better than 0.1%



Exceptionally compact and light in weight the Type 5206 resistor units of *very high stability* are hermetically sealed in metal cases. Designed for use where resistances up to 10 MΩ are required, the units meet the specifications laid down in R.A.E. Spec. G.1177 and satisfy the tests described in Spec. R.C.S. 11.

Rating: 500 V per MΩ
Temperature coefficient : ± 20 parts per million per °C at room temperature

Time constant: Approximately 10^{-6} seconds
Max voltage: 500 V d.c.

Write for full details to:

H. TINSLEY & CO. LTD. Werndee Hall, South Norwood, London, S.E.25 tel : Addiscombe 6046-8

TY 2

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LONDEX

RELAYS

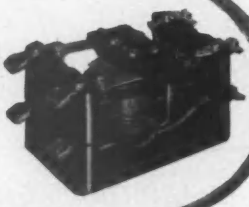
in thousands of variations

SMQ

A miniature mercury switch relay. Rating up to 20A. S.P.D.T. Coils up to 110v D.C. or 250v A.C.

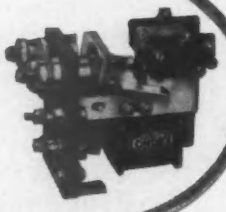
MOL

A small relay with moulded base and insulators. Contacts up to 3 amps. T.P.D.T. Coils up to 165v D.C. or 450v A.C.



LF/STR

A heavy current contactor for low voltage switching. Rating up to 100A at 24v. S.P.S.T. Coils up to 250v D.C. or 600v A.C.



For emergencies and breakdowns we can supply many types of relays with 200–250v A.C. coils from stock.

LONDEX LTD.

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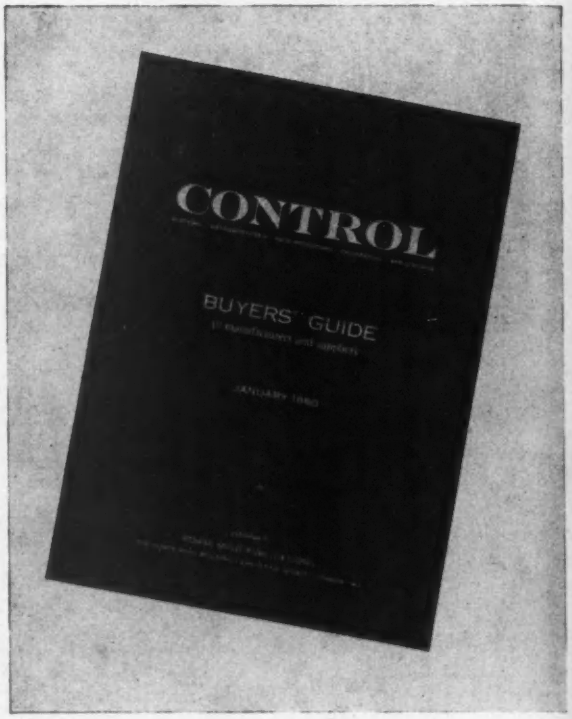

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THE ROWSE MUIR BUILDING,
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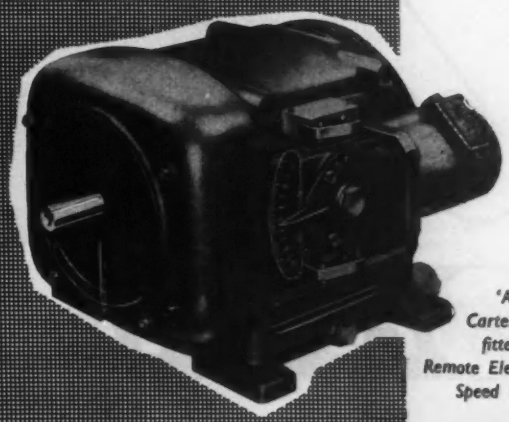
Carter Hydraulic Variable Speed Gears

Smooth stepless speed variation from input speed down to zero r.p.m. with accurate control by Handwheel, Remote Electrical or Lever arrangements.

Carter Variable Speed Gears may be used to pick up loads from zero r.p.m. and speed control setting may be adjusted with the drive running or stationary.

Manufactured in ten sizes for fractional up to 40 horsepower drives.

Write for Folder 1660.



'A' Type Carter Gear fitted with Remote Electrical Speed Control

Carter Gears Limited BRADFORD 3 YORKSHIRE ENGLAND

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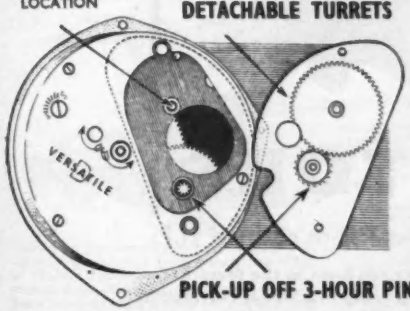
The 'VERSATILE' Chart Recorder Drive

Electrical or Mechanical

CHART HUB LOCATION

INTERCHANGEABLE and EASILY DETACHABLE TURRETS



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Makers of Precision Gears

All types up to 8" diameter
10 to 64 D. P.

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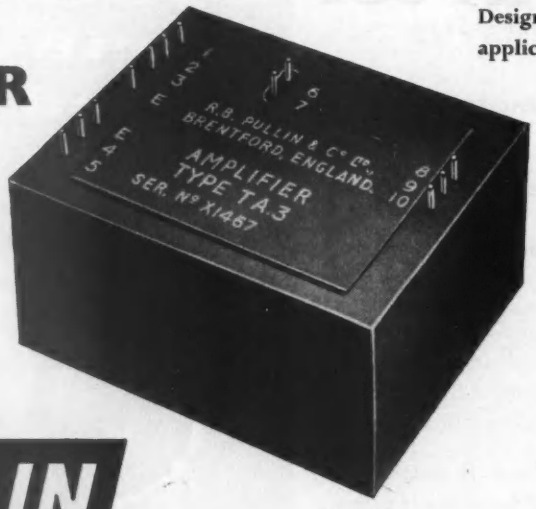
A NEW SERVO AMPLIFIER by PULLIN



The TA3 is the latest addition to the Pullin range of servocomponents. Designed for all servo control system applications where arduous conditions at a wide ambient temperature range exist, the transistor servo amplifier provides a power output of up to 6 watts at 65°C and 4 watts at 70°C without any additional heat sink. The unit operates from a balanced 26 volt 400 cycles A.C. supply or from 18 volts D.C. and is ideally suited for driving size 10, 11 and 15 motors and motor generators.

Leaflet giving full details will gladly be sent on request.

Synchros · Servo Motors
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Servo Gearboxes

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PHOENIX WORKS · GREAT WEST ROAD · BRENTFORD · MIDDLESEX
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ALSO MERCURY SWITCH UNITS FOR HAND OR MECHANICAL OPERATION AND MERCURY SWITCH RELAYS

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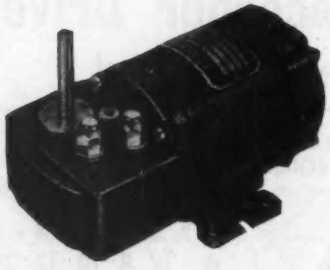

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from 1/250th to 1/3rd H.P.

We have been in the forefront of developing Fractional Horsepower Motors for the past 25 years in the industrial field, and are able to meet the large variations in demand.

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Agents: S. Birchall, 31 Maldon Drive, Monton, Eccles, Manchester Eccles 1084
Law & Plumtree, "Glenholme", Holme Road, Matlock Bath, Derbys. Matlock 326
DsF860C

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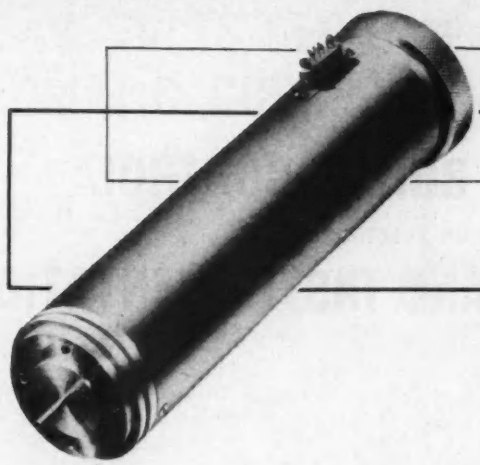

ALLSCOTT TYPE 259T LINTRAN

Mains frequency Transducer

For remote measurement of process variables or as a measuring element in inspection type comparators.

Basically, the Lintran is a differential transformer with a moving core operating in a specially designed electro-magnetic circuit which obtains adequate sensitivity and accuracy by operation at mains frequency. It can be used with any physical quantity capable of producing a proportional physical displacement—pressure, temperature, etc. Linearity—better than ±1% with 1 Kilohm load. Output ±150 mV undirectional into 1 Kilohm load.

James Scott & Co ELECTRICAL ENGINEERS **Ltd**

Manufacturing and Electronics Division

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Shettleston 4206

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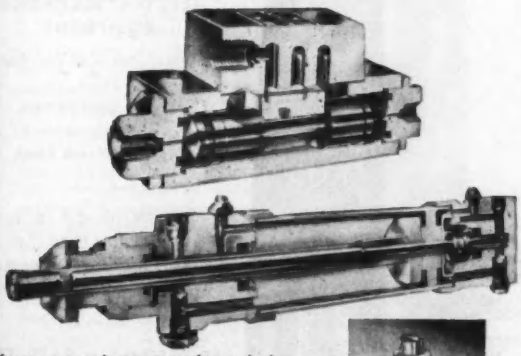
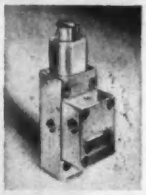
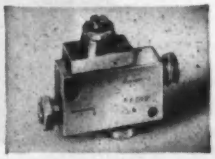
THE MOST COMPREHENSIVE RANGE OF

PNEUMATIC CONTROL EQUIPMENT



You cannot get a better range of control valves, cylinders and air line fittings than that made by Midland Pneumatic Ltd., *because no better range is made.* As their design is based on many years' practical experience in the application of industrial pneumatics, we claim the range is as comprehensive as any on the market. Why not judge for yourself by writing for a copy of our latest catalogue and asking for a representative to call?





MIDLAND PNEUMATIC LTD
NEW CROSS · WOLVERHAMPTON

Telephone: 32501/2

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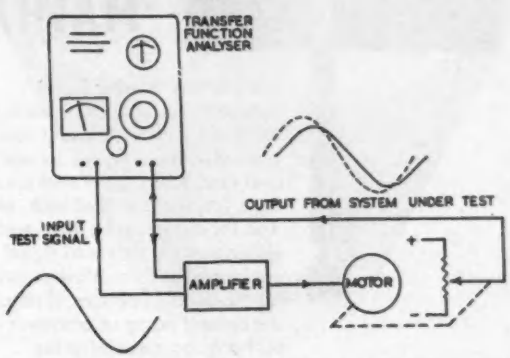
Made easy and accurate with Servo Consultants Transfer Function Analysers and Automatic Nyquist Plotters.



These versatile instruments may also be used for :

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- ***Mechanical input system testing***
- ***Hydraulic and Pneumatic Servo testing***

We also manufacture Very Low Frequency Generators, Process Analysers and a Standard Range of Servo Gearboxes.

For full details write to :

Servo Consultants Ltd.

17 Woodfield Road, London, W.9. Tel. CUN 7073

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AUTOMATIC BUNKER LEVEL CONTROL

MAIHAK

The Maihak Bunker Level Indicator automatically controls the filling level of fine and coarse grained bulk mass such as coal, coal dust, grain, plant husks, sawdust, soap flakes, dried milk, etc. The Indicator can be fitted with either acoustic or visual signal equipment and the Maihak switch on the paddle operates, if required, the control pump or conveyor carrying the material to the Bunker.
Complete details available from Sole Sales and Service Representatives in Gt. Britain and Ireland.

MAIHAK

SMAIL SONS & CO. LTD.

21/23 INDIA STREET, GLASGOW, C.3

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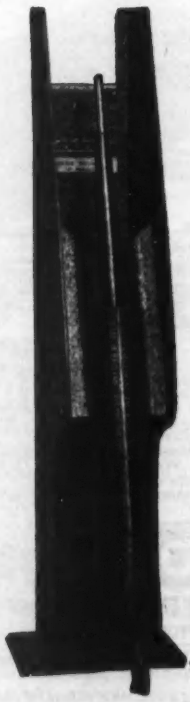
THE ELECTRONIC INDUSTRIES SOLDERING TOOL FOR THE TRANSISTOR AGE etc.

ADCOLA (Regd. Trade Mark)



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ELECTRIC SOLDERING EQUIPMENT

Manufactured in all Volt Ranges from 6/7 to 230/50 Volt with elements Insulated from Earth

A PRODUCT FOR PRODUCTION
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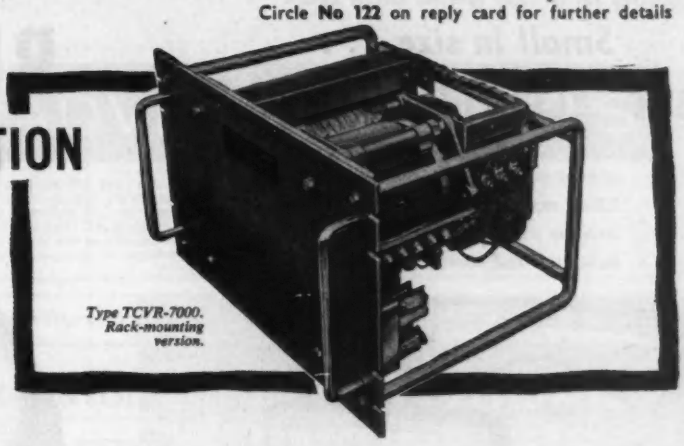
40 VOLTS/SEC AUTOMATIC CORRECTION

—with the type TCVR voltage regulator



Type TCVR-7000. Rack-mounting version.

The TCVR is a servomechanical automatic voltage regulator having the very high speed of correction of FORTY VOLTS PER SECOND. It provides an *undistorted* output, maintained constant within very close limits (normally ±0.5%) from no-load to full-load, for wide variations in frequency and power factor.

A wide range of models from 1.6 to 12 kVA single-phase, and 4.8 to 36 kVA three-phase, is available, to standard or tropical specification, in cabinets or for rack-mounting. Models are also available in which the output voltage is continuously adjustable over a wide range by means of a panel control. Regulators can be supplied to Services' specification, and special models can be designed to order.

For high-speed, accurate stabilisation *without distortion*—**specify TCVR.**

Claude Lyons Ltd

Other products of Claude Lyons Ltd. Stabiliser Division

BMVR: Motor-driven laboratory and industrial regulators ranging from 1·6 to 29 kVA single-phase, and 4·8 to 87 kVA three-phase. Constancy of output normally ± 0·5% from no-load to full-load. No distortion. Speed of correction 1 Volt/Sec. A great variety of models, standard, tropical and militarised, for all applications.

BAVR: Electronic stabilisers of very high accuracy, and very rapid response, with no moving parts. Input range: − 10% to + 5%, output constancy ± 0.15%. Three sizes: 200, 500 & 1000 VA. Exceptionally useful for control of chemical processes, heating, lighting, etc.

ASR: Automatic step regulators, small, inexpensive, and with sinusoidal output waveform. Two sizes: 1·15 kVA and 2·3 kVA. Input range − 10% to + 5%; output constancy, ±2½%.

ATC: Automatic Tap-Changing Transformers — a development of ASR. Two sizes: 575 VA and 1150 VA. Input range − 20% to + 10%: output constancy, ± 5%. Provide adequate stabilisation for many types of apparatus, at low cost. Also useful as pre-regulators, e.g. in conjunction with BAVR.

We shall be pleased to send you full details of our entire range.

Stabiliser Division **VALLEY WORKS · HODDESDON · HERTS · TELEPHONE HODdesdon 4541-4**

CL/47/E2B

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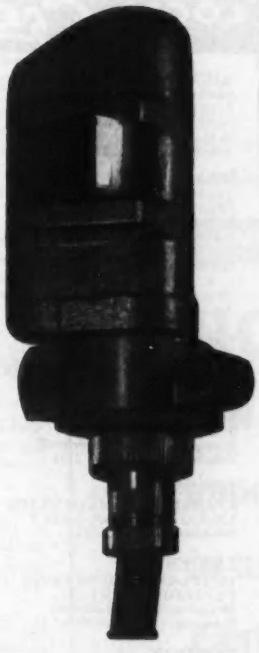
This photo-Electric Cell and Housing has been designed for use in conjunction with the Print Registration Control Unit for the "Watford" Mark I Overwrapping machine and the Type "B" Batch Counter.

Because of its compactness and simplicity of design it has been found easily adaptable for all kinds of work requiring a registration system. The housing is of an aluminium alloy casting giving great strength and at the same time being extremely light in weight. The finish is in matt black stove enamel — or to customer's requirements.

Length 5¼"
Width 2"



Precision Engineers Ltd.
Colonial Way, Station Estate, Watford, Herts. *Telephone Watford 26259*

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For accuracy, ease of reading, robustness, economy and long, trouble-free life install Rototherm Thermometers, Controllers and Recorders. Specialists in bi-metallic applications.
Write for details.

Rototherm

BI-METAL · MERCURY-IN-STEEL · VAPOUR PRESSURE
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Merton Abbey, London, S.W.19 — LIBerty 7661
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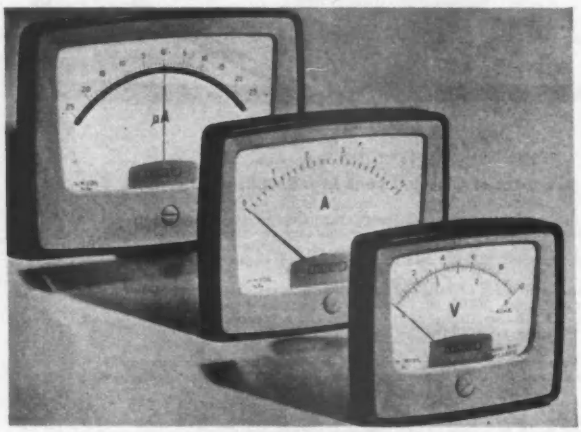
Small in size . . .

but "ELLIOTT-ACCURATE"

The introduction of these three new models completes the famous Elliott range of miniature instruments. Small in size . . . crystal clear in indication and consistently Elliott-accurate!



Electrical Measurement Division

ELLIOTT BROTHERS (LONDON) LTD

Century Works, Lewisham, London, SE13 · Tideway 1271

A member of the Elliott-Automation Group

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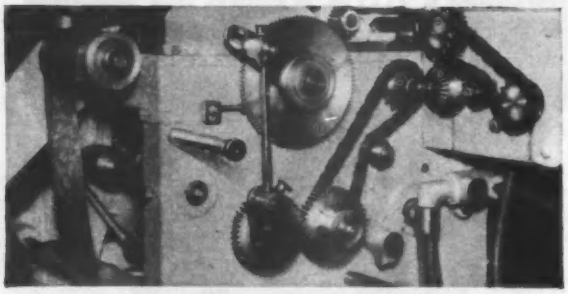
RENOLD Sprag Clutches



transmit more torque for size and weight than any other clutch

for *INDEXING

as illustrated on this toffee wrapping machine. The sprag clutch is used for indexing the paper feed drives which also employ Renold ·375" pitch simple roller chain.

***Renold sprag clutches index with speed and accuracy—and to infinite graduations—limited only by the precision of the other components of the machine.**

Write for catalogue giving details of our comprehensive range of over 70 standard sizes for indexing, back-stopping and silent over-running with low drag.

RENOLD

RENOLD CHAINS LIMITED
SPRAG CLUTCH UNIT
58, CATHEDRAL ROAD
CARDIFF

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"CORREX" TENSION GAUGES

The only instrument solely designed for accurately measuring tension on *Relays, Contacts, Switchgear*, and electrical apparatus of all kinds. Gauge measures in grammes, and a large range of sizes is produced to cover from 0.3–2,000 grammes.
Swiss made and guaranteed.

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See Advertisement on page 15

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BOX Nos.:— 1/- extra will be charged

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to be members of a development team engaged in the engineering to small batch production stages of basic designs from scientific groups. The work in some cases will include environmental testing.

Applicants should have served an engineering apprenticeship or have had equivalent training and be Corporate Members of a Senior Engineering Institution. A good knowledge of electronic development work particularly in the field of fast pulse techniques is necessary and experience of transistor circuitry and digital computer work would be an advantage.

SALARY:—£860–£1,825 p.a. according to age, qualifications and experience.

Superannuation Scheme. A house or substantial assistance with house purchase will become available for married officers living beyond daily travelling distance.

For application form please send postcard (or letter) to the

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quoting ref. A2604/309.

Vacancy for

CHIEF OF TEST AND INSPECTION

to be responsible to the Chief Engineer for quality control at all stages of manufacture and test of Electronic Products.

Previous experience essential. This is a responsible position in a rapidly expanding organisation. Contributory pension scheme. Salary according to age and experience.

Applications giving full details of experience, age and qualifications to the Chief Engineer,

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BRISTOL Aircraft

ELECTRICAL ENGINEERS

The opportunity for making a career with Bristol Aircraft Ltd., presents itself to men with sound electrical experience who have a degree or H.N.C. (Electrical).

These posts are in the Electrical Systems Group of our Aircraft Design Office at Filton, and deal specifically with problems relating to the design and operation of electrical equipment and systems. The problems are varied and interesting and should provide a challenge to men of creative ability.

If you are interested in making a career for yourself with a progressive organisation then please write to:

J. RAIMES, ROOM FW/7/CON,
BRISTOL AIRCRAFT LIMITED,
FILTON, BRISTOL,

who will arrange an interview for you with the Head of our Electrical Systems Group.

A MEMBER OF BRITISH AIRCRAFT CORPORATION

NOW

new opportunities in automatic control

Sales Engineers
In Marketing Divisions and Area Offices

Application Engineers
Customer liaison and project engineering

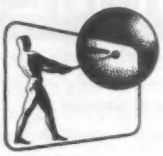
Design Engineers
Equipment and system design

Development Engineers
Circuit and application investigations

Technical Writers
Technical information preparation

You should be 25 to 35, have knowledge and experience of industrial electronic control and allied techniques and the desire to join a hardworking organisation that has already grown twenty times larger in ten years.

Write to Ref. ST3,
Lancashire Dynamo Electronic Products Ltd., Rugeley, Staffs.



RANK PRECISION INDUSTRIES LIMITED

CENTRAL RESEARCH LABORATORIES

have vacancies for

DEVELOPMENT ENGINEER

to work on problems connected with the Xeronic Computer Output Printer. Electro-Mechanical, Optical, and Hydraulic principles are involved in these developments.
Applicants should have experience in one or more of these fields and a minimum qualification of HNC or equivalent.

ASSISTANT

An assistant is also required in connection with the above developments and for testing of prototypes. A man with adequate practical experience of equipment testing and maintenance, together with ONC or equivalent, would be preferred. Ex P.O. or Radar Mechanic might suit. Salary in the region of £750 with opportunity for improvement.
Staff pension scheme is in operation and salaries are reviewed annually.

Please apply in writing, giving details of qualifications and career so far to:

The Laboratory Manager,
Rank Precision Industries Ltd.,
Central Research Laboratories,
Sulgrave Road, Hammersmith, London, W.6.

SATURN

The largest Analogue Computer in Europe with 1,500 amplifiers is now being commissioned by the English Electric Co. Ltd., at Whetstone, near Leicester.

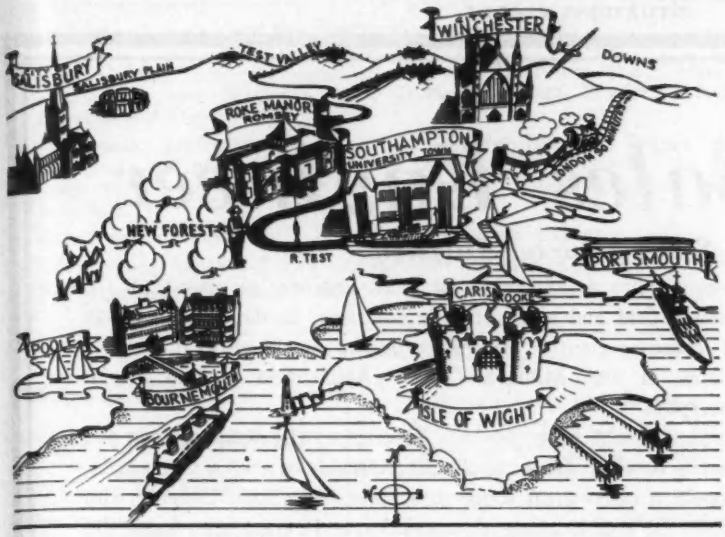
Men with experience in using Analogue machines are required now to prepare problems for this machine and the smaller 200 amplifier 'Mars'.
Solution of problems, previously too large for Analogue Computers is now possible and a team is being built up to tackle stimulating and difficult problems in:

(a) *Reactor control and stability studies in two and three dimensions.*
(b) *Simulation of complete power station and its control.*
(c) *Time dependent stress problems in two and three dimensions.*
(d) *Testing of hardware in conjunction with the above simulation.*

The new English Electric, fast scientific digital Computer (1. Microsec and 14. Microsec mult.) will be available together with two English Electric Deuce Computers which will be used in conjunction with Saturn.
Men experienced in numerical analysis and programming will find ample scope for their capabilities.

'ENGLISH ELECTRIC'

Reply giving details of past experience and salary to:
TECHNICAL STAFF OFFICER, DEPT. G.P.S., MARCONI HOUSE, LONDON, W.C.2.
Quoting Ref. C 1806E



Electronic Research

AT ROKE MANOR

Several responsible positions have been created by the expansion of the research programme in the following fields:—

Digital Storage—aimed at both increasing the speed of existing computer memory systems, and at devising new storage techniques, which include low temperature systems, tunnel diode storage elements, and new ferrite structures.

Speech Bandwidth Compression—a study of methods of transmitting the information content of speech, including formant tracking, etc.

Evaluation of New Solid State Devices—an examination of the circuit possibilities of solid state devices such as tunnel diodes, Boff diodes, impact ionisation diodes, cryotrons, and new transistor devices.

Roke Manor is organised to stimulate and encourage original ideas, and is ideally situated in wooded parkland on high ground overlooking Romsey. There is an active social and sports club whose outdoor facilities include tennis, cricket, volley ball and sailing. A wide choice of residential areas includes Southampton, with its excellent educational facilities and shops, and the many delightful villages around Romsey, the Test Valley and the New Forest.

Applicants should have a 1st or 2nd class honours degree in Engineering or Physics or be of equivalent standard. Some research and development experience in the computer field is desirable for the digital storage work but emphasis will be placed on original thinking and willingness to assume responsibility. Publication of papers is encouraged.
Starting salaries range from £1,000 to well over £2,000. The higher salaries will be offered not only to those assuming responsibility but also to those making significant contributions to the field.

Plessey

Apply in confidence to the PERSONNEL MANAGER

THE PLESSEY COMPANY LIMITED

Roke Manor, Romsey, Hants.

Mullard

MULLARD LIMITED
Semiconductor Division

Sales Engineer

for Semiconductor Division

Mullard require a semiconductor Sales Engineer to operate in the computing field and to assist their customers in the design of high speed transistor circuits. He will be backed by the effort of over 45 graduates in the Mullard Circuit Application Laboratory at Southampton.

Applicants should have previous experience with transistors in the computing or allied fields and should preferably be not less than age 25.

The position offers great scope to a successful circuit designer who now feels the urge to apply his conviction and experience outside the laboratory.

This is a key position in the electronic industry and the successful applicant cannot fail to make himself a master of his subject.

Written application should be sent to:

Personnel Officer, MULLARD LIMITED, Mullard House, Torrington Place, London, W.C.1.

AEI

ASSOCIATED ELECTRICAL INDUSTRIES LIMITED
MOTOR AND CONTROL GEAR DIVISION

The Control Gear Engineering Department at Manchester have vacancies for Electrical Engineers for work covering the design and application of Motor Control Gear using modern techniques to a wide range of industries. Applicants familar with electronic and equivalent apparatus applied to closed loop control schemes, static switching or logic circuitry would be preferred.

Applicants should be graduates of the I.E.E. but consideration will also be given to men with lower technical qualifications who have the appropriate background.

Please write giving full details of age, experience qualification and salary required, quoting reference E.16 to:—

Personnel Manager,
Associated Electrical Industries (Manchester) Ltd.,
Trafford Park,
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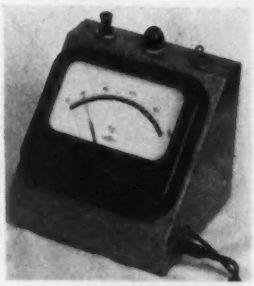

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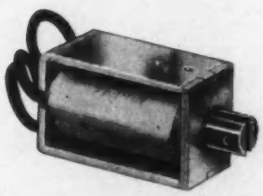

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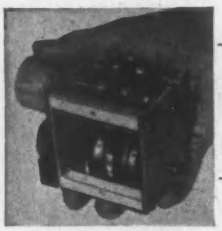

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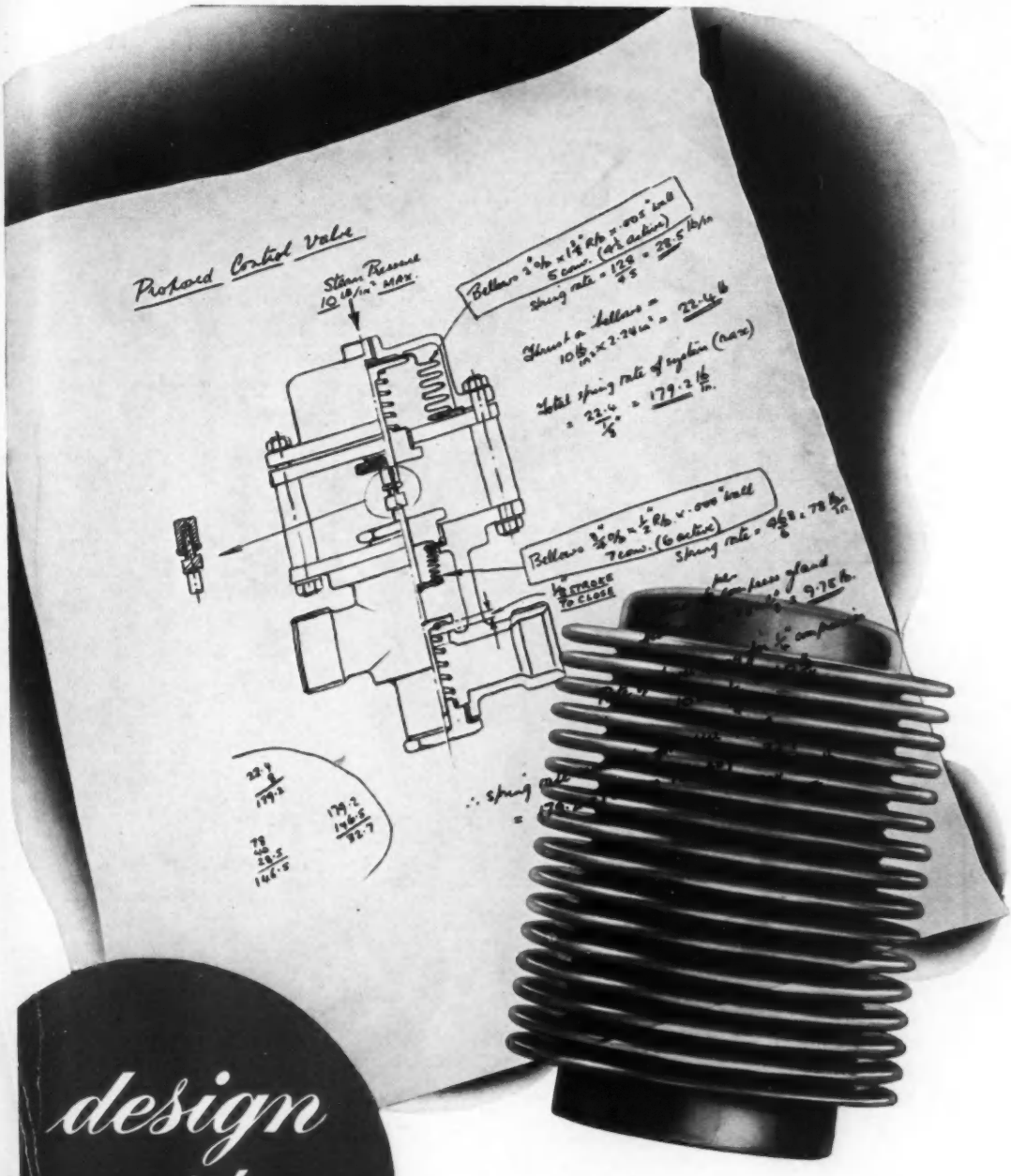

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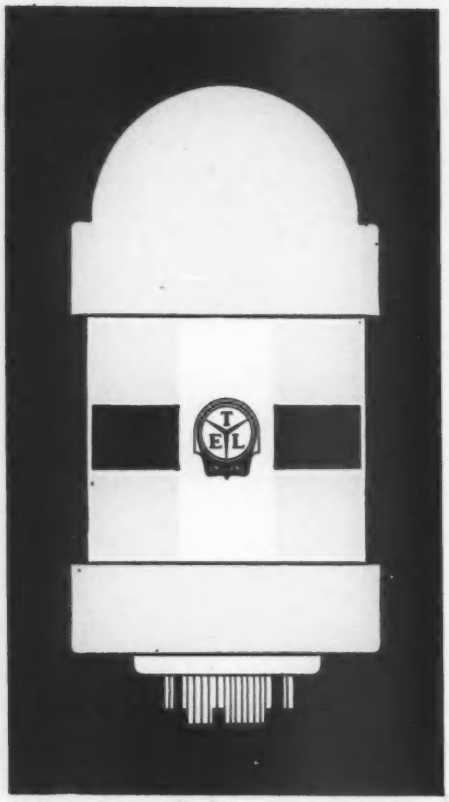

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